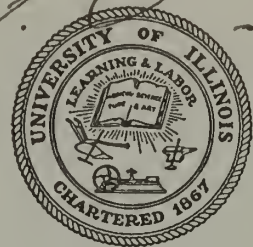


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EVALUATION OF ALTERNATIVE WASTE TREATMENT FACILITIES

By

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FEDERAL WATER POLLUTION CONTROL

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ABSTRACT

Objective methodology for combining the essential aspects of engineering technology, economics, and social value judgment to evaluate possible waste treatment alternatives has been lacking traditionally. This work attempts to collate these three areas to produce a method that will allow engineers to plan waste treatment facilities systematically and objectively, at the same time being able to incorporate in their plans some measure of society's esthetic needs and desires.

The terms "water quality" and "water pollution" have been defined and related quantitatively. Pollution has been defined as the difference in concentrations of two sets of quality, the raw waste quality and the quality desired of the effluent from the proposed waste treatment plant. A benefit-cost analysis has then been proposed to be applied to the pollution list of constituents and concentrations thereof to be removed. Benefits of removing different constituents to different levels are to be compared to the costs of attaining these various removals through several possible alternative treatment processes. Intangible values and elusive secondary benefits have been included in the economic arithmetic in an objective fashion.

An hypothetical problem has been developed in some detail to demonstrate the method's applicability, as well as its advantages over the traditionally more subjective approaches.



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I. INTRODUCTION

OBJECTIVE

The evidence is not convincing...that the practice of pollution control--which essentially is concerned with an allocation of water users--has kept pace with the needs of our expanding economy, either in terms of philosophic approach or practical accomplishment. In some places the pressures for getting something done about pollution have too often obscured the reasons for doing it. Quite obviously, unless the objective is in focus, the administration and practice of pollution control must suffer from confusion, frustration, and ineffectiveness (20).

So said Edward J. Cleary (20) in 1961. He went on to say that "...a stream may be called upon to serve many uses, some of which are in conflict. The basic problem in pollution control, as I see it, is to establish rational procedures for reconciliation of these conflicts" (20). It is the development of such a procedure that is the objective of this work.

Why is such a procedure needed, and what are the basic factors involved? The recent and continuing (1965-1967) scurry of the state governments to establish water quality standards in compliance with the Water Quality Act of 1965 highlights the underlying problem. As Mr. Cleary has suggested, the nation has grown and pollutional sources have concentrated so rapidly that the sanitary engineer has found that both his technology and philosophy could not change quickly enough to keep up.

Water-borne epidemics caused early attention to be given to producing potable water for home use, and municipal and industrial water treatment facilities have been improved again and again in the wakes of

public indignance, fear of water-borne catastrophe, and competitive urges to produce better and better things for less and less money. Today the water treatment industry can spend more of its time and effort removing the slightest of esthetic nuisances to produce a product that is not only safe but highly pleasing to the customer. The absolute necessity of safe water for the community, then, drove the engineering profession to expand its philosophy and its technical competence commensurately with the growth and expansion of the public itself.

Waste treatment, on the other hand, was not so crucial to public and private well-being; and in this area, the profession must admit, it let its fervor slide. No blame is intended here, nor is it felt warranted. The fact simply is that we did what we could to take the lumps out of waste water and to keep it from stinking, but we knew that downstream there were fine, new, water treatment facilities that could adequately remove the killers and stainers, so why should we do more?

Twenty to fifty years ago there was little reason to do more. All of a sudden, today, there is reason; and we do not know exactly how to do more because we "wasted" those years as far as waste treatment is concerned making water treatment better and better. But today, the public has decided, pollution has gone too far; we must curb it; limits must be set. Through its representatives the public has called on the sanitary engineers (by law the states' sanitary engineers, but tacitly to all of us) to set those limits. Presumably

we engineers should know better than anyone else what these numbers should be and how compliance with them can be assured; and we probably do. Unfortunately we do not know many of these things as certainties, and what is lacking in technical competence or knowledge must be made up for in judgment, philosophical refurbishing, and new methods for doing a more modern job of waste treatment and management.

Again, what are the basic factors involved in such a procedure? They are three: engineering technology, basic economics, and social value judgments. Superimposed on these three areas of concern is the necessity that the procedures be simple, workable, and reasonable. They cannot be effective if they are academic exercises. Perhaps twenty years from now today's academic research will become applicable to real-life situations, but by then the stop-gap measures of today will have curbed the brunt of the problem by necessity. Today's procedures must be those that operate reasonably well, if not theoretically purely, in a vacuum of necessary data and meaningful cause and effect relationships.

The procedure developed here has little historic theory to support it. It is presented as an aid to guide engineers through judgments about water uses and their quality requirements. If it demonstrates, as is intended, that there are more uses of wasted water than there are of municipally supplied drinking water and, therefore, more constituents of importance at a waste treatment plant, then it will have served both engineering technology and its underlying philosophy.

SCOPE OF THE PROBLEM

Countless authors have said that water pollution control planning should be predicated on the uses for which the water in question is intended. Also a great number of authors have said that water resources planning should be comprehensive. Fortunately, both statements are most probably true. Unfortunately, few, if any, authors have presented methods through which pollution control planning was indeed predicated on water use, and only a few authors have been able to plan a water resources project even remotely as comprehensively as they believed possible at the outset.

The central hypothesis on which this thesis is based is that there must exist a yet undefined procedure by which pollution control measures may be implemented with regard given to water use, quality criteria, benefit-cost analyses, and serving the public good in the most beneficial way possible. It is the writer's objective to devise such a procedure.

The search here is for a "planning" rather than a "management" aid. For the purposes of this paper, planning shall be the engineering-economic-political process that leads to a choice among alternatives of waste treatment facilities. Water quality management, by distinction, will be the more purely engineering-administrative machinations required to put the chosen alternative into existence and proper operation. From a technical, engineering point of view, "planning" continues through the first designs and preliminary report; when the final selection from among the possible set of alternative courses of action is made, final designs are completed, and we begin to "manage" water quality by constructing and operating the physical plant. It is a procedure to

guide the evaluation of the alternatives that concerns us here.

For numerous reasons, devising a procedure of this type will not be simple. There are, first of all, countless considerations to be weighed; pollution control planning is a complex business. Table 1 includes a few of the factors to be weighed; there are many more that the reader may want to add. Furthermore, if the solution to the planner's problems were simple and absolute, procedures of this type would have been elucidated long ago. Still further there is the problem of testing such a procedure, which requires that data as complete as the procedure demands exist for at least one real situation. Unfortunately, such data do not exist to the writer's knowledge, and until they become available the procedure must rest on its intrinsic value, which is to point out quantitatively 1) that good water is better than bad water, 2) what makes a water good and what makes it bad, and 3) what the alternatives are for making a bad water good.

Fortunately, the procedure derived herein indicates by its very nature what particular data must be collected in a given situation. Strangely its greatest value may lie in its leading to its own improvement. A hypothetical case is developed to demonstrate the procedure's use.

TABLE 1
NOBODY SAID POLLUTION CONTROL WOULD BE EASY

Pollution control planning must encompass:

Affiliations	Political Decision Making
1. Public	Primary and Secondary Benefits
2. Private	and Costs
Antagonisms	Professionalism
Assimilation	Public and Private Welfare
Data Available	Quality Standards
Dilution	Reasonableness
Distance	Spatial Relations
Economies of Scale	Synergism
Effluent Charges	Tangible and Intangible Benefits
Equity	and Costs
Esthetics	Technology
Hazard	1. "Water" Treatment
Imponderables	2. "Waste" Treatment
Legitimate Users	3. Data Collection and Analysis
People	Time

II. ANALYSIS OF THE LITERATURE

The purest derivation of a new method for doing anything requires considerable background material to establish a need, a theoretical base, a step-wise procedure, and a reasonable test for the method. In preparing a water pollution control planning method one might not be so lucky. The groundwork is voluminous but lies all around the question, and the data for testing a very complete method do not exist. In short, no one has derived a simple but workable method before. Computerized solutions of mathematical models are, to be sure, becoming numerous; but they are too complicated for everyday use, or they are applicable to only very special cases, or they conflict with established policies for treating pollution problems.

The existing literature, however, can lead us to some conclusions about what methods are needed and perhaps what philosophical peculiarities have kept them from being developed before now. Most importantly we shall try to find supporting evidence for a newer, modern philosophy that reduces on paper to an equation or a method that can be solved to produce a plan for abating pollution.

As was noted earlier there are three areas of concern that should be included in the method if it is to be useful: technology, economics, and social value judgment.* These three areas will be discussed as separate topics here, but those who believe that they can be completely compartmentalized simply do not understand the problem.

*This is not the old catch-all, "engineering judgment." That is included in technology.

Indeed their inexorable intertwining is partially responsible for our continued search for a simple method for considering pollution control.

Furthermore, in discussing and reviewing the history of each of these areas we must consider simultaneously both the philosophy and the techniques of implementing these attitudes that led or did not lead to a satisfactory solution. If there is evidence that present philosophies lack the accompanying techniques for their implementation, then we must develop a new scheme for including, as best we can, a technique that will get the job done reasonably well. If techniques presently available will economically and satisfactorily abate pollution but are not being used because the philosophy of the day does not require their use, then perhaps our method should expand the philosophy to include these techniques and others that may develop.

This effort, it should be pointed out, is being made by an engineer. The objective is to develop a method to be used by other engineers. The review of literature, then, begins with engineering problems and solutions surrounding water pollution. In Chapter I terms were used such as "water pollution control" and "water quality management." The Water Quality Act of 1965 was mentioned as well as the limits or standards that this law requires to be set. Part of the objective of the study was to develop a method for planning collection of data as well as for their use. We should review these things, then, to see how they fit into present engineering attitudes and procedures for engineering pollution away.

Next we shall review economic policies and procedures to derive a basis for inclusion of financial factors in the method to be developed. We must find out what benefits and costs are involved with pollution abatement, and how they are presently evaluated and manipulated. We should further explore whether engineering know-how and dollars can be, or are in the absolute, related to standards of quality or levels of utility. If there is such a relationship, can we incorporate it in the procedure we are seeking? Still further we should review and learn the applicability of economic objectives such as optimization, efficiency, and minimization of cost, and the essential elements of time and interest rates.

Social value judgment is something of which engineers are probably not fully aware in their everyday work. Nonetheless they indulge in it freely, if tacitly, with every design they make. The final judgments in the matters of greatest good for the greatest number, public versus private welfare, and the esthetic values of water are not really the engineer's to make. They belong to the public, who, in theory at least, does make the final choice. However, for the engineer to present to the public or its representatives reasonable alternatives of design from which to choose, he must and does make both knowledgeable and arbitrary decisions of a social kind. The method to be developed here will include a formalizing of this decision process for the engineer's benefit, and we shall review in this chapter what methods are available to him.

Finally we shall see, hopefully, from what we have reviewed and other sources that a method for quantifying "quality" and "pollution"

is needed very badly. From this conclusion and what we have learned from the literature we shall begin to develop the method in the following chapter.

ENGINEERING TECHNOLOGY

Quality and Pollution

Before getting very far we are confronted with problems of definition. What are "quality management" and "pollution control"? Are they the same things or are they even related? More basically, what are "quality" and "pollution"? Most importantly, what are they to an engineer?

The term "water quality" generally is used to connote the collective state of water that is desired or has been attained as a final product by a specific user for his specific purpose or purposes of using that water. "Pollution," on the other hand, usually refers to the presence of just one or perhaps several individual substances in water that are in at least one way objectionable to at least one user of the water as it occurs in nature. Rarely if ever does a "quality" list appear that corresponds to a "pollution" list. Most engineers think of quality and pollution as two different sets of things.

A glossary (63) of terms used in water and sewage treatment practices was prepared in the late 1940's and gave the definitions this way:

Quality, Water.--A term used to describe the chemical, physical, and biological characteristics of water in respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another depending upon its characteristics and the requirements for the particular use.

Pollution.--The addition of sewage, industrial wastes, or other harmful or objectionable material to water.

Faust (38) also decided that "quality" depends on the use to which water is put. He discussed drinking water quality specifically at some length, mentioned the increased importance of improving "consumer aspects" of water such as taste and odor, staining, color, corrosion, turbidity, and temperature, and decided ultimately that the AWWA task group on water quality criteria had answered the question, "What is quality water?" (38), better than Faust could himself. The report of this task group (8) was written by Elwood L. Bean. Bean felt that, "It is doubtful that any two people would agree as to what represents a quality water" (8). The same is probably true of "pollution," and it might be argued that this is reason enough to cease discussion of both terms. Nonetheless, Bean and his task group attempted a definition of quality, and Hartung (54) has reiterated it later. The definition of "functionally ideal water" given by the task group is as follows, and though it is specifically for drinking water, it is probably as good a definition as can be found.

Ideally, water delivered to the consumer should be clear, colorless, tasteless, and odorless. It should contain no pathogenic organisms and be free from biological forms which may be harmful to human health or esthetically objectionable. It should not contain concentrations of chemicals which may be physiologically harmful, esthetically

objectionable, or economically damaging. The water should not be corrosive or incrusting to, or leave deposits on, water-conveying structures through which it passes, or in which it may be retained, including pipes, tanks, water heaters, and plumbing fixtures. The water should be adequately protected by natural processes, or by treatment processes, which insure consistency in quality (8).

Bean felt (8) that it is likely that few waters meet such an ideal specification, and furthermore that laboratory techniques today are in some cases inadequate to determine this anyway. However, he presented a table of maximum concentrations for a number of constituents and indicated that if these concentrations were not exceeded, the water would "approach the functional ideal." His table (8) included six physical characteristics, ten toxic and eleven nontoxic chemical substances, three scaling and corrosion inducers, three radiological characteristics, and coliform density as the one bacteriological index.

Ackerman and Löf (1) presented data on the quality of water as it occurs in streams. Their table entitled, "Water Quality: Chemical Analysis of Representative Surface Water Supplies in the U. S.," included pH, silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, total dissolved solids, total hardness, and specific conductance. It is interesting, however, that in their table entitled, "Organic Pollution of Surface Water at Selected Streams," they listed (1) values of temperature, dissolved oxygen content, 5-day BOD, and coliform organisms in MPN/100 ml. Still other data of these authors presented a similar contrast between the constituents of good water and those of bad water. In their table, "Tolerance of

Specific Water Uses for Different Types of Water Supply," for each use of water they gave indications of tolerance for dissolved solids content, turbidity, bacterial count, temperature, and mode of occurrence (ground water or surface water)*. In yet a fourth table, however, describing waste discharges from different industries, which are certainly large contributors to increased pollution and lower water quality, these authors (1) listed only BOD and suspended solids. Many articles and books have regarded water quality and water pollution similarly, as though they were only vaguely related concepts.

In a subjective discussion of stream quality, Gabrielson (43) came as close as anyone to connecting the two concepts. He said (43), "The minimum quality at any point in a water source must be based on the most critical requirements of all the uses to which that water may be put including fish, wildlife, and recreation." By implication water of lesser quality could be considered polluted. It is undeniable that such water could contain some constituent that would be in low enough concentration to render it unusable only for drinking purposes and not for other purposes. Still, according to most definitions, such water would be "polluted." Thomas (114) has also pointed out that when using the term "water resources" people usually are thinking

*Generally reports of data on "ground water quality" contain concentrations of constituents other than those listed in reports on "surface water quality" (73) (74), regardless of the intended or expected uses of either type. Admittedly, however, experience of the investigators and practicality in sampling may have led to these distinctions in a valid way.

of a product that is 99.95 percent pure and rejecting water that is less than 99.5 percent pure. In other words, "quality" water in nature usually has a dissolved solids content of no more than 500 mg/l, and "polluted" water contains 5000 mg/l of dissolved solids or more.

Coulter (23) has related the two terms with a definition of pollution, as opposed to Gabrielson's (43) vague implication that pollution defines quality. He said (23), "When a quality characteristic is found to endanger health, increase the cost of use, be objectionable to the general public, interfere with uses, or limit the opportunity to use water, pollution exists." Stroud (108) has also called pollution, "the specific impairment of water quality by domestic, industrial, or agricultural wastes (including thermal and atomic wastes) to a degree which has an adverse effect on beneficial use of water, yet which does not necessarily create an actual hazard to the public health."

Many definitions of "pollution" are available that do not connect this concept with that of "quality." McKee and Wolf have said (89) that any substance that can be present in water is a "potential pollutant--potential in the sense that, if concentrated sufficiently, it can adversely and unreasonably affect such waters for one or more beneficial uses; and yet, if diluted adequately, it will be harmless to all beneficial uses." This definition implies that water may contain substances in concentrations that adversely affect the beneficial uses

of water, but not so adversely as to be unreasonable. According to these authors (89), then, adverse effects on the use or user of water, resulting from the quality of the water being less than adequate, are apparently necessary but not sufficient to show pollution. This definition is stronger than those of Stroud (108) and Gabrielson (43).

Stroud (108), however, "rephrased" his definition of pollution in the same article mentioned above, and it came out sounding even more harsh than that of McKee and Wolf (89). Stroud said, "...water is polluted when there is anything in it that keeps people from drinking it, swimming in it, fishing in it, boating on it, or using it, as is, for industrial purposes" (108) -

Stroud's (108) rephrased definition is extreme, and perhaps was made that way for effect, but it seems to be so demanding as to be unreasonable. Nonetheless the point will be made later that this definition of Stroud's is as close as anyone has come to giving the engineer the definition he needs to work with pollution. Still, although his restated definition is consistent with the philosophy that all water has some quality other than pure, either good, bad, or in between, if it were applied to any single body of water, his criteria as restated could actually conflict. There are water quality necessities for some industries that would render the same water unsuitable for fish life, and the same or other industrial requirements are likely to render the water unpalatable. Also it is generally considered that water that has been bathed in or boated upon is not suitable for drinking purposes without prior treatment. Unpolluted water conforming to Stroud's second definition, then, may be difficult

to find in nature and is likely to be almost as difficult to produce by any type or degree of treatment.

Gross (51) defined pollution from a legal standpoint. He stated that, "Only when the interests involved in the use of the stream outweigh the interests involved in the placement of the discharge do we have pollution" (51). It is interesting that Gross also reported (51) that "...courts have gone beyond the law itself and have determined that although elimination of pollution would be desirable, as a practical matter only the abatement or reduction of pollution can be accomplished." The courts have decided, then, in terms of Gross' definition, that as a practical matter the interests involved in using the stream will always be greater than the interests involved in discharging waste substances to the stream; and hence, there will always be pollution. This is reminiscent of the definition of McKee and Wolf (89) including both adverse and unreasonable effects on the stream and of Stroud's implication (108) that all natural waters are to some degree polluted.

The law(s) beyond which the courts have gone and to which Gross referred are primarily those of the state legislatures (all states do not have such laws), which laws in their literal sense generally do not permit any discharge resulting in "pollution." These laws are designed to protect both private and public interests in the stream, but in the case of conflicts they recognize the public interest as the greater need. The individual statutes recognize certain public interests that are to be protected and which may or may not include public health, animal and aquatic life, and recreational, agricultural,

and industrial uses of the stream. "Pollution" generally is defined by these statutes, then, as the placing of a discharge into a stream that is harmful to a specified public interest (51).

In North Carolina sixteen major river basins have been subdivided and classified according to user requirements, and a concomitant set of water-quality standards has been assigned to each classification, which has become a matter of law (58). According to Hubbard (58), "...'pollution' is, therefore, defined to mean a condition of such waters which is in contravention of the standards established and applied to such waters in accordance with the classification system."

Probably the one constituent of water that receives the most attention as an indicator of pollution is dissolved oxygen. Worley, Burgess, and Towne (135) made an interesting connection between water quality and pollution while discussing dissolved oxygen. They said (135), "Dissolved oxygen concentration long has been used as a criterion for water quality because of the wealth of information available on its reaction kinetics in water and the ways in which pollution affects it." Ackerman and Löf (1) have said of D.O. content, "Generally any value below 75 percent [saturation] suggests the existence of 'pollution' which makes the water undesirable for human consumption. The lower the percentage the more unsuitable the water is."

The Department of Health, Education, and Welfare, through the U. S. Public Health Service, conducted a conference in August, 1963, for discussion of interstate pollution of rivers flowing from Georgia into Alabama. The record of that conference (119) contains a very interesting discussion of pollution. A report had been prepared

by the U. S. Public Health Service concerning the quality of the Coosa River System, and this report had been read into the record of the conference. The general conclusion of the lengthy report was that the Coosa River was polluted by the time it reached the Georgia-Alabama line where it flows from Georgia into Alabama. Four characteristics had been used to determine this state of pollution, not all of which appeared adverse at the state line, although the others were incriminating enough to elicit the conclusion that the river was polluted. The four standards were dissolved oxygen, pH, coliform count, and some biological investigations.

Dr. John Venable, then Director of the Georgia Department of Public Health, questioned the U. S. Public Health Service officials connected with the study about the fact that the standards used to evaluate pollution were not all exceeded. The following colloquy between Dr. Venable and Mr. John Thoman of the U. S. Public Health Service resulted.

MR. THOMAN: ...pollution can be a series of parameters which fall below certain accepted or legal standards. The three or four that were investigated here and written up merely relate to the important ones in this particular case.

In other situations it could well be something, such as chlorides. It could be cyanides; it could be any sort of other toxic material. Now just because the waters of the Chattanooga and the Coosa at the state line in both cases did not meet all of these criteria or, for a fact, they didn't meet maybe a thousand other criteria, or did meet a thousand other parameters; if there is no dissolved oxygen in the water, it is polluted regardless of what the pH is, the chlorides are, the pesticides, or any other one thing that is in there. [Emphasis added.]

* * * * *

DR. VENABLE: Mr. Thoman, you mentioned legal standards. Would you give me some indication of what legal standards apply in a case of this character.

MR. THOMAN: There are no legal standards which apply in this particular case.

DR. VENABLE: But you referred to legal standards?

MR. THOMAN: Some states do have legal requirements for certain materials.

* * * * *

DR. VENABLE: You say that water with no dissolved oxygen is polluted, per se; is that your statement?

MR. THOMAN: I would think that would be a correct interpretation; yes.

DR. VENABLE: What about the Army Engineers, who release water from Alatoona Dam with absolutely no dissolved oxygen in it when it's released; is this polluted water?

MR. THOMAN: If the damages can be demonstrated; yes.

DR. VENABLE: Is it polluted? I agree with you, it can cause damage; but is it polluted?

MR. THOMAN: If damages occur.

DR. VENABLE: Thank you.

(Reference 119, pp. 177-179)

In 1965 Pfeffer (94) wrote that, "For the control of pollution, it is necessary to include all pollutants and not single out one." Here we have another word, "pollutant." The use of this word implies again that any one thing can cause pollution to exist. It is encouraging to note from Pfeffer's article (94), though, that attention is being turned to all the constituents of water that are detrimental, rather than attacking them one at a time.

Finally in 1966 a definition of pollution appeared, this one by Haney (52), that was supposedly an engineer's definition. Haney called pollution "...the impairment of water quality, with resultant significant interference with beneficial water use" (52). It is a good definition for a layman. Even for engineering purposes it is close to workable; but Haney felt the need to qualify it, and the qualification was needed. He said that the matter of significance was open to conflict and that we may have to resort to a judge and jury to help us decide what "significant interference" is. Unfortunately, because he and the others have retained the political aspects of the generic term, pollution, engineers still do not have a term with which they can operate in a purely analytical fashion. Earlier it was said that politics, economics, and technology are involved concomitantly with pollution abatement; but during the process when the engineer is doing his share of the technical planning he must have a way to deal with and consider pollution as a parameter that can be altered or manipulated. Decisions whether to pull a tooth, fill it, or leave it alone are not referred to judges and juries; dentists--trained professionals--make these decisions and act accordingly. Pollution and the engineer are not yet related in this way.

Water Quality Standards

The determination of acceptable levels of certain constituents in desired finished waters, meant for a multitude of uses, leads logically to defining water quality for each use in terms of quality criteria or quality standards. For some reason(s) considerable controversy has

raged over the years as to which term, standard or criterion, should be used, if either. Proponents of another argument have sided either with effluent standards or with stream standards, and most of the combatants are convinced that one regulation is reasonable, the other unusable. These adversaries have decided, at least, that some standard, criterion, ideal, goal, requirement, or objective of water quality is logical and necessary. This writer would agree. The federal government has already agreed through the Water Quality Act of 1965 (123).

To begin with the semantic problem of standards vs criteria, it should be pointed out that most authors use the terms interchangeably, and indeed Webster's Dictionary (126) indicates that the difference in meaning is academic. Nonetheless, several authors (8) (88) (89) (133) have insisted that there is a fundamental difference and that this difference must be preserved. Standards, they feel, are the law; they are rigid, autocratic gospels that with time become associated with ideal conditions. Criteria, on the other hand, are just "yardsticks," guidelines, rules of thumb, "ball park" figures that can be updated and manipulated by judgment and not by an act of Congress. It is apparently all right also to plan and design with engineering-office criteria that are based on judgment, as well as they are, or as much as they are, on scientific evidence; but it is not right that these same numbers become law until there is considerably more scientific evidence to support their validity.

Although there is some merit in this position, this writer would point out that if a distinction is to be made, there is a better reason to do so. Just as there is a difference between those numbers for each constituent that appears in the U. S. Public Health Service

Drinking Water Standards (118) and those in the AWWA specifications of "Ideal Water" (8), so too could there be a difference between the federal natural water quality standards and a set of as yet un-adopted professional objectives for natural water quality. The law of the land should regulate to promote satisfactory water quality and to prohibit dangerous or undesirable water quality. Professional goals, on the other hand, should be established that will promote good or excellent natural water quality if at all possible. In this context there might be reason to make the distinction of terms.

This semantic argument notwithstanding, what role do water quality standards play in water pollution control planning, specifically the engineering part of this process? The answer depends on who you are, or what sort of project you are working on now. If you are a consulting engineer or a sanitary engineer employed by an industry and have been asked to design a waste treatment facility, then the state standards are likely to be your entire basis of design (31). If you work for a governmental agency you may have the question reversed somewhat and be trying to determine what the standards should be to protect "the plan" that has already been proposed. If you are designing a municipal water treatment plant, you will probably ignore the legal standards (118), since they are so easy to meet, and simply do the best you can, hoping that the finished water will have a quality approaching "ideal" (8).

But what purpose is served by standards that are viewed differently by different engineers? There follows a review of some

of the written discussions concerning the efficacy of standards, both pro and con.

In 1960 Zapp (137) discussed physiological effects of organic contaminants in water. He stated that in all studies of toxicity it had been possible to find levels of dosage so small that "the characteristic toxic effect of the material does not appear within the normal life span. This includes even the chemical carcinogens." He also pointed out, however, that the "experts" cannot agree to a "safe" level of ingestion for human beings. Speaking specifically of the chemical carcinogens, Zapp said (137), "...when the experts...who are best qualified to judge do agree that a safe level of intake for any of them can be assigned, the law should permit a tolerance to be established." For most organic contaminants, Zapp felt that it should be possible to determine safe levels of concentration, and that these levels should be "finite rather than zero." He concluded (137) that, apparently, "...we have the tools required for the evaluation of safety...and we know the means for reducing these contaminants to safe and acceptable levels. If this knowledge is applied..., it should be possible to avoid even minimal physiological or toxicological effects." The avoidance of such effects is unquestionably the salient purpose for which quality standards are ever established.

However, there are other reasons for them. Also in 1960 McKee (88) made a poignant observation describing an inevitable decline in water quality caused by increases in population and intensified industrialization. He said, "The trend must be combated and slowed by rigid

control of industrial wastes, by regulation of resource development, and by treatment of municipal wastes, but it cannot be stopped or reversed..." (88). [Emphasis added.] Water quality standards appear as the most logical and effective means of control and regulation, even if they only serve to slow the decline that McKee implied must come.

In 1960 Gabrielson stated (42), "A national system of water quality standards from a health, recreational, industrial, and aquatic life basis should be developed and accepted by all units of government. These standards should be enforced vigorously and uniformly. Damage and loss should not be required as proof of pollution." In 1965 Gabrielson reiterated (43) this view, and it was reinforced that same month by Stroud (108). Stroud said that if precise standards were adopted, "For the first time, through provision of specific goals of cleanliness, it will give meaning and substance to the hitherto nebulous philosophy of keeping water as clean as possible. For practical purposes, it defines what 'possible' is. For the first time, too, we shall have a firm basis for legal action. It would be necessary to show only that a polluter violated the standards--not that he killed fish, as at present" (108). Both Gabrielson (43) and Stroud (108) felt that standards or criteria must be set that will protect against extreme environmental conditions and that will guarantee favorable conditions for the survival of the most sensitive organisms in the water-resource system.

In 1963 the Public Health Activities Committee of the Sanitary Engineering Division of ASCE published a progress report (22) in which the Committee discussed coliform standards for "recreational," primarily bathing waters. The report repeatedly made the point that no scientific, epidemiological basis exists for any value of such a standard yet proposed. The report left the impression that since no scientific basis is available, then perhaps such standards should be discontinued altogether. Ruskin (102), in his discussion of this report in 1964 felt that having no scientific basis was not sufficient grounds to cease monitoring coliform organisms or even to stop enforcing arbitrary standards. He argued that if coliform standards are not good, then they should be replaced by better ones, not discarded. Some standard, he argued, albeit intuitive or empirical, is necessary and better than none (102). In its closure (22) of the published report the Committee agreed that some reasonable criteria should be established on the basis of epidemiological evidence. The reasons the Committee cited for this conclusion were "the cost of waste treatment required to meet these standards, the relative uncertainty of methods for destroying coliforms in sewage effluents, the strong probability that coliforms do not reflect the total health risks involved, and the growing problem of contamination of recreational waters by uncontrolled and largely uncontrollable sewer overflows" (22).

Weston (128) presented the views of industry toward water quality standards. Because water pollution control apparently presents industry with a reduction in profits, Weston reported that the national industrial viewpoint "subscribes to the philosophy that pollution should

be evaluated on the basis of socio-economic effects as well as effects on water quality per se" (128). Protesting the concept of as much treatment as possible, Weston (128) said, "This concept is subject to arbitrary rather than rational decision making. It can be uneconomical and mysterious, confusing and frustrating to those subject to its enforcement." The criteria developed, according to Weston, should be "as specific as possible" and "reasonable, equitable, measurable, enforceable, and enforced." Furthermore, their enforcement should be "reasonable, equitable, forceful, consistent, and persistent" (128).

It is notable that Weston felt that specific criteria could be reasonable and equitable and, at the same time, enforceable and enforced. In arguing their semantic question, McKee and Wolf (89) took a more negative approach: "The fact that a standard has been established by authority makes it quite rigid, official, or quasi-legal. An authoritative origin does not necessarily mean that the standard is fair, equitable, or based on sound scientific knowledge..." (89). Later they said, even of criteria, "Among water-quality criteria there are few if any that can be considered absolute and final, for absolute truth is a rare thing" (89).

In 1965 McGauhey (87) discussed the unscientific basis for establishing water quality standards. He felt that although there must always be a certain amount of "folklore" inherent in the standards that are set, nonetheless, it is imperative that engineers be able to quantitate water quality. Consequently if standards be "folklore," then make the most of it; they must be established.

The Water Quality Act of 1965 (123) having been adopted makes much of this discussion of efficacy less relevant than it might otherwise be. The engineering profession may have debated this question in perpetuity, but now that the scramble is on to propose and approve the federal standards, even credible negative arguments have lost much of their sting. It remains to be seen how effective the adopted standards will be, and if engineers will continue to design waste treatment plants just to comply with these standards or whether they will adopt professional goals that are more stringent than the letter of the law, as they have done in water treatment plant design.

Stream Surveys

When this thesis was still being conceived, the first question of interest was, "Are we presently measuring the proper constituents of water to allow us to plan for future water resource allocation?" The question has narrowed at this writing to, "What constituents of natural water must an engineer measure or have knowledge of, and what can he do or should he do about the numbers he finds?" The method for evaluating treatment plant alternatives to be derived herein should answer this question.

In a recent article (25) a problem requiring the use of a specific stream survey was succinctly posed this way: "The question was to what degree industrial and municipal wastes were affecting water sports and fishing...." The article then described the survey that was conducted; measurements were made of D.O., pH, temperature, specific conductance, MPN's, BOD, ammonia, nitrate, and nitrite. Thirty-four months and \$150,000 later the author (25) was not able to answer the original question; at least he did not propose an answer in his article.

Apparently this inability to answer the basic question is common. DeFalco (27) has written, "Eutrophication of lakes, tastes and odors, the red tides, acid mine drainage, and unexplained fish kills are common manifestations of water pollution. At the present time these are only vaguely related to measurements which in a quantitative manner can be relied on to demonstrate effectiveness of control measures." He says further (27) that this thing that is too frequently absent, "the ability to relate the public's desire for clean water to measurable characteristics or impurities in water," is the first and most rudimentary element of water pollution control. In short, we often do not measure the right things in water simply because we do not know what the important constituents for a given use or user are.

So what should we measure? Tsivoglou et al. (116) have indicated that this depends on the primary objective of making the survey at all. The purpose may be one of several things: obtaining background data, control of waste discharges, preliminary evaluation of an existing situation, research and development of new information, or "simply the obtaining of data for the record" (116). Weaver (124) and Murphy (83) have said that a stream survey should, among other things, delineate man-made from natural levels of pollution. This is apparently another way of saying that surveys can determine "background" levels of constituents.

Weaver (124) warns that the tendency exists to "look at everything" to avoid overlooking some constituent that might be important.

This, he says, "is an insidious trap--almost always unsound, technically as well as economically." It is interesting to note, however, that Weaver (124), as well as Coulter (23) and others (48) (49), has pointed out that hundreds or even thousands of measurements may be required; and furthermore that above and beyond the laboratory analyses performed, information about climatology, economics, geophysics, hydrology, population, and present and projected water uses must also be gathered.

In discussing the problem of making so many costly measurements, even if they are necessary, Green (48) makes a distinction between "surveillance" and "monitoring." Surveillance applies to measurements made of the stream's quality to ascertain whether the stream condition has improved, worsened, or stayed the same, particularly with regard to stream quality standards that may now or one day will pertain. Monitoring, on the other hand, refers to individual plant surveys--tests of specific effluents to check the effectiveness or efficiency of a particular waste treatment facility. It is interesting to note that Green (48) has made the connection between effluent and stream standards that has probably always existed, although each has been adamantly supported and the other condemned by many authors. Green was discussing the stream standards to be established by the Water Quality Act of 1965, however, when he said that a successful program of effluent monitoring will lessen substantially the amount of necessary stream surveillance, which is extremely costly "even for minimal coverage" (48). He went on to say, "...the less the amount of public money spent on the surveillance operations, the greater the amount available for the more productive cleanup efforts attainable

through construction of adequate waste treatment plants" (48). Still a certain amount of both monitoring and surveillance will be necessary both to design an adequate treatment facility in the first place and to assure the adequacy of its operation in the second. As Weaver (124) said so well, "Regardless of how much money is spent on treatment plants, on research, on other control activities, if the stream quality is not satisfactory we know that present programs are either inadequate or ineffective."

Present Design Practice

Too many authors to enumerate here have said that either a water or a waste treatment plant should be designed, built, and operated to prepare water for subsequent use or reuse. This attitude is so ubiquitous, indeed, that it can be accepted as fact and truth: treatment facilities are built to enhance usefulness of water.

Waste treatment facilities, however, do not always accomplish this purpose (65) (81) (83). Why is this? The main technological reason probably is that sanitary engineers have slowly become convinced that reusability of wastewater is related almost exclusively to low contents of BOD, suspended solids, coliform organisms, and maybe one or two other things. Certainly if a waste containing some obviously dangerous substance, such as cyanide or arsenic, is to be treated, then these special problems are included in the design as well. But some less conspicuous, though important, quality parameters often get overlooked, for example chloride (81), color (65), or algal nutrients (83).

Another established principle of engineering is that water and waste treatment are intimately related; that one contributes to the other; and that each should be a part of a "regional program" that includes the other (35). However, the disparity that actually exists between listed quality requirements for many users of natural water (89)(118) and the normal operational standards for waste treatment plant effluents (BOD and suspended solids) makes these statements more platitudinous than axiomatic. This interrelationship of water to be used and water to be discarded has simply never been proposed as an engineering equation or set of equations. It has been said that such relationships are sorely needed (20)(21)(91)(92), and the method proposed herein attempts to define some of these relationships.

Present technology is adequate to purify water or to treat wastes to any degree of perfection desired, yet pollution in the generic sense still exists and is getting worse. A large part of the reason for not providing a higher degree of treatment is the belief that "secondary" biological treatment is "complete" treatment and that additional, "tertiary" processes are too expensive to be feasible anyway. We come now to an exploration of the economic considerations of waste treatment and pollution abatement plans.

ECONOMIC CONSIDERATIONS

It is interesting to note that the noun, "economics," means "the science that investigates the conditions and laws affecting the production, distribution, and consumption of wealth, or the material

means of satisfying human desires; political economy" (126). The adjective, "economical," on the other hand, means, among other things, "managing or managed without waste; frugal; thrifty; provident" (126). Its synonym is "sparing." The one word seems most involved with allocating wealth or distributing benefits, while the other denotes preoccupation with minimizing expenditures or costs. Perhaps it is not so surprising, then, that persons involved with water planning have such strongly opposing views about what we can afford to do and what we cannot. Nonetheless there is an established but growing policy of the federal government regarding its water resource developments, their water quality aspects, and the economic evaluation of such projects that rather well states the direction and degree of future public expenditures in the area of water planning.

Federal Policy

In May, 1950, the Federal Inter-Agency River Basin Committee adopted a report of its Subcommittee on Benefits and Costs concerning "Proposed Practices for Economic Analysis of River Basin Projects" as a basis for consideration by the participating agencies for application in their individual activities in river-basin planning. In 1954 the Inter-Agency Committee on Water Resources succeeded the Federal Inter-Agency* River Basin Committee, and the duties of the Subcommittee on Benefits and Costs were continued by the new Subcommittee on Evaluation

*At that time the agencies included the Departments of Agriculture; Army; Commerce; Health, Education, and Welfare; Interior; and Labor; as well as the Federal Power Commission.

Standards. The original report was revised and reprinted by the latter Subcommittee in May, 1958 (97). The chairman of this Subcommittee during 1958, Eugene W. Weber, has later had this to say about the report: "...Of greater practical effect in the 1950's was the completion of the Federal Inter-Agency report on 'Proposed Practices for Economic Analysis of River Basin Projects' which, though never formally agreed to by the agencies, was nevertheless put into practice, at least in part, by most agencies concerned and brought about considerable improvement in the formulation and evaluation of water plans" (125).

It is in fact interesting to read some of the statements of the agencies concerned appended to the revised report in which these agencies make clear that, though they favor the adoption of the report "as a basis for consideration" (97), they do not necessarily agree with all the practices proposed therein. The statement of the Bureau of the Budget is particularly strong on this point. It may be noted that the Bureau of the Budget was not an official member of the Inter-Agency Committee, although it is likely a standard procedure for the Bureau to review any policy statements or proposals concerning the Federal economy. Furthermore the Bureau had prepared in 1952, in conjunction with other agencies, its own Circular A-47 (34) in which it also had attempted to establish a consistent procedure and policy for evaluating proposed Federal water-resource activities. Therefore, regardless of standard Bureau procedures, it was expedient for the Inter-Agency Committee to solicit the views of the Bureau concerning

the revised report. Though Dixon (29) states that Circular A-47 was "the controlling Federal water-resource-policy documentant [sic] for at least a decade" (29), the revised report of the Subcommittee on Evaluation Standards, known familiarly as the "Green Book," apparently has been much more widely available, and generally has had more universal impact on water-resource planning.

The latest and currently most important statement of policy concerning economic evaluation of water-resource projects is Senate Document 97 (95). This statement of "Policies, Standards, and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Land Resources" was prepared jointly by the Secretaries of the Army, Interior, Agriculture, and Health, Education and Welfare. This document, ordered to be printed in 1962, naturally contained many of the elements and suggestions of the Green Book, but of greatest importance, the heads of the four Departments were unanimous in their recommendations, and the provisions of the document were to be applied consistently by each of the four Departments in the discharge of their respective water-resource activities.

These two documents, the Green Book and SD-97, define many benefits and costs, be they direct or indirect or otherwise associated with the project formulation. For purposes of this discussion the many types of benefits and costs accruing from or incurred by water-resource projects need not be redefined, except perhaps those that may arise subsequently in relation to water quality. Dixon (29), who gives a good

summary of these many definitions as they appear in SD-97, makes the point that the evaluation of benefits and costs in the manner proposed in that document leads directly to the computation of a benefit-cost ratio. He further states (29) that calculation of such a ratio is required by only a few Federal agencies and very few state, local, or private agencies; but because it reduces the evaluation ultimately to a single figure, this type of computation is being more and more frequently employed at every level of government, as well as in private practice.

The following direct quote from the Green Book establishes the basic principles and concepts of economic evaluation of any water-resource project, whether water quality is of direct concern or not. It should be noted that the statement takes cognizance of the fact that many benefits cannot be measured in monetary terms.

The ultimate aim of river basin projects and programs, in common with all other productive activity, is to satisfy human needs and desires. The objective of economic analysis in planning river basin and watershed programs is to provide a guide for effective use of the required economic resources, such as land, labor, and materials, in producing goods and services to satisfy human wants by determining whether economic resources would be used more effectively than would be the case without the project.

Although it is recognized that public policy may be influenced by other than economic considerations, this report is concerned with the economics of project development and justification.

To be most effective, the economic analysis must be oriented to be consistent with the following principles:

(1) The goods or services to be produced by a project have value only to the extent that there will be need and demand for the product.

(2) The most effective use of economic resources required for a project is made if they are utilized in such a way

that the amount by which benefits exceed costs is at a maximum rather than in such a way as to produce a maximum benefit-cost ratio or on some other basis. Maximization of net benefits is a fundamental requirement for the formulation and economic justification of projects and programs.

(3) The project as well as any separable segment or increment thereof selected to accomplish a given purpose should be more economical than any other actual or potential available means, public or private, of accomplishing that specific purpose.

(4) From an economic standpoint the order in which a number of projects should be undertaken should be used on their relative efficiency in use of economic resources. The economic analysis should, therefore, provide data which can ultimately be used for comparing the economic desirability of a number of justified projects. In this comparison consideration should be given to the relative significance of effects which cannot be measured in monetary terms. It should be recognized also that the selection of a project for development may change the relationship of remaining projects in the array since the project undertaken may affect the relative efficiencies of the remaining projects.

(Reference 97, p. 5.) [Emphasis added.]

The later and more current document, SD-97 (95), is generally in accord with the Green Book with regard to economic policy except that some of the benefits discussed in the Green Book as intangible (those that cannot be expressed in monetary terms), particularly those involving water-quality enhancement and pollution abatement, are more clearly defined and are more definitely included as "primary" or "direct" benefits in SD-97. The statement of objectives of planning in SD-97 is given below. The more definite language of this document, while maintaining the same interests described in the Green Book, presents an interesting contrast to the earlier document in that it reflects

the growing concern of the Federal government, pursuing and accompanying the aroused interest of the general public, for the social values of water as well as its economic worth. There are those who feel that these values are inseparable (5)(113), although "priceless" is still probably as descriptive as "beautiful." The difficulties of evaluating wholesomeness notwithstanding for the moment, the pertinent statement of policy from SD-97 (95) is as follows:

The basic objective in the formulation of plans is to provide the best use, or combination of uses, of water and related land resources to meet all foreseeable short- and long-term needs. In pursuit of this basic conservation objective, full consideration shall be given to each of the following objectives and reasoned choices made between them when they conflict:

A. Development

National economic development, and development of each region within the country, is essential to the maintenance of national strength and the achievement of satisfactory levels of living. Water and related land resources development and growth, through concurrent provision for--

Adequate supplies of surface and ground waters of suitable quality for domestic, municipal, agricultural, and industrial uses--including grazing, forestry, and mineral development uses.

Water quality facilities and controls to assure water of suitable quality for all purposes.

Water navigation facilities which provide a needed transportation service with advantage to the Nation's transportation system.

Hydroelectric power where its provision can contribute advantageously to a needed increase in power supply.

Flood control or prevention measures to protect people, property, and productive lands from flood losses where such measures are justified and are the best means of avoiding flood damage.

Land stabilization measures where feasible to protect land and beaches for beneficial purposes.

Drainage measures, including salinity control where best use of land would be justifiably obtained.

Watershed protection and management measures where they will conserve and enhance resource use development.

Outdoor recreational and fish and wildlife opportunities where these can be provided or enhanced by development works.

Any other means by which development of water and related land resources can contribute to economic growth and development.

B. Preservation

Proper stewardship in the long-term interest of the Nation's natural bounty requires in particular instances that--

There be protection and rehabilitation of resources to insure availability for their best use when needed.

Open space, green space, and wild areas of rivers, lakes, beaches, mountains, and related land areas be maintained and used for recreational purposes; and

Areas of unique natural beauty, historical and scientific interest be preserved and managed primarily for the inspiration, enjoyment and education of the people.

C. Well-being of the people

Well-being of all the people shall be the over-riding determinant in considering the best use of water and related land resources. Hardship and basic needs of particular groups within the general public shall be

of concern, but care shall be taken to avoid resource use and development for the benefit of a few or the disadvantage of many. In particular, policy requirements and guides established by the Congress and aimed at assuring that the use of natural resources, including water resources, safeguard the interests of all of our people shall be observed.

(Reference 25, pp. 1-2.) [Emphasis added, except for headings.]

The specific economic policy for formulation of plans stated in SD-97 is more expansive than the portion of the Green Book reproduced above, and includes, besides the stipulation that net benefits be maximized, that each separable unit or purpose shall provide benefits at least equal to its costs, that tangible benefits shall exceed project economic costs, and that there shall be no economically justifiable alternative means of accomplishing the same purpose that would be physically displaced or otherwise precluded from development if the project were undertaken (95).

Other pertinent stipulations of SD-97 include time, interest rates, and price levels. The period of analysis is considered to be the shorter of either the physical life or the economic life of the facility, with the stipulation that 100 years will normally be taken as the upper limit. The interest rate to be used in converting benefits and costs to a common time basis "shall be based upon the average rate of interest payable by the Treasury on interest-bearing marketable securities of the United States outstanding at the end of the fiscal year preceding such computation which, upon original issue, had terms to maturity of 15 years or more" (95). If this rate is not a multiple

of one-eighth of 1 percent, the next lowest multiple of one-eighth of 1 percent shall be taken as the rate of interest. Prices to be used in economic evaluations are to be those prices that are expected to prevail at the time the expected costs are incurred or benefits are accrued.

But what are the specific policies of the Federal government regarding water quality? Over the years national water policy has concerned itself primarily with water quantity, although water quality considerations have been mentioned or implied as being necessary and of value, but primarily as intangibles. Benefits accruing from water pollution control were mentioned finally in the 1958 revision of the Green Book, but had not been included in the first edition of 1950. The 1958 edition mentions pollution abatement considerations such as the elimination of public health hazards and esthetic improvements as being of "controlling importance in the justification of pollution abatement" (97), but apparently not necessarily in the justification of the project itself. The Green Book further states that "economic indicators" of the benefits of water pollution abatement, to be used in lieu of identifiable market values for the evaluation of such benefits, include the cost of the most economical alternative means of accomplishing the same purpose, reduction in costs of municipal or industrial water treatment, and improvements in recreation facilities resulting from improved water quality and quantity (97). Notice the retention of "and quantity," rather than "or quantity," or even "and/or quantity."

Municipal and industrial water supply, however, was given a heading of its own in the Green Book under which it is explicitly stated, "...Improvement of water supply may result either from an increase in the quantity or an improvement in quality of the available water" (97). [Emphasis added.] Still, a nuance in the writing of this section of the Green Book is worth noting. The authors state that from an overall public viewpoint, a municipal or industrial water supply development can be economically justified if the cost is, again, less than the cost of the most likely alternative means of producing this water in the absence of the project. But the section on water supply is closed with "...The general basis for evaluation is essentially the same as that set forth in greater detail above for electric power" (97). This suggests that as late as 1958 the writers of national water policy were still most concerned in their thoughts and everyday activities with navigation, flood control, hydroelectric power, and perhaps irrigation water quantity; and quality aspects of water-resource planning were only included summarily. This should be of particular interest to sanitary engineers, as it speaks rather poorly for their participation and influence in national affairs affecting their profession so directly as does water-resource planning and evaluation.

The increased emphasis on the basic needs of the population for water of suitable quality, as well as on the esthetic values of water, was reflected at the Federal level in SD-97. The language of that document placed far more importance on both the tangible and intangible benefits accruing from water quality improvements than had any

previous statement of policy emanating from as many Departments of the Executive branch of our government. According to SD-97 primary benefits accrue to water-resource development through the following purposes for such development, listed here as in that document in apparently preferential order: domestic, municipal, and industrial water supply; irrigation; water quality control; navigation; electric power; flood control; land stabilization; drainage; recreation; fish and wildlife; and other benefits.

The primary benefits and proposed standards for their evaluation as given in SD-97 for those purposes of development most closely concerned with water quality are given below.

[1] Domestic, municipal, and industrial water supply benefits: Improvements in quantity, dependability, quality, and physical convenience of water use. The amount water users should be willing to pay for such improvements in lieu of foregoing them affords an appropriate measure of this value. In practice, however, the measure of the benefit will be approximated by the cost of achieving the same results by the most likely alternative means that would be utilized in the absence of the project. Where such an alternative source is not available or would not be economically feasible, the benefits may be valued on such basis as the value of water to users or the average cost of raw water (for comparable units of dependable yield) from municipal or industrial water supply projects planned or recently constructed in the general region.

[2] Water quality control benefits: The net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality. The net contribution may be evaluated in terms of avoidance of adverse effects which would accrue in the absence of water quality control, including such damages and restrictions as preclusion of economic activities, corrosion of fixed and floating plant, loss or downgrading of recreational

opportunities, increased municipal and industrial water treatment costs, loss of industrial and agricultural production, impairment of health and welfare, damage to fish and wildlife, siltation, salinity intrusion, and degradation of the esthetics of enjoyment of unpolluted surface waters, or, conversely, in terms of the advantageous effects of water quality control with respect to such items...[Intangibles may be approximated by the costs of achieving the same results by the most likely alternative.]

[3] Recreation benefits: The value as a result of the project of net increases in the quantity and quality of boating, swimming, camping, picnicking, winter sports, hiking, horseback riding, sightseeing, and similar outdoor activities...In the general absence of market prices, values for specific recreational activities may be derived or estimated on the basis of a simulated market giving weight to all pertinent considerations, including charges that recreationists should be willing to pay and to any actual charges being paid by users for comparable opportunities at other installations or on the basis of justifiable alternative costs. Benefits also include the intangible values of preserving areas of unique natural beauty and scenic, historical, and scientific interest.

[4] Fish and wildlife benefits: The value as a result of the project of net increases in recreational, resource preservation, and commercial aspects of fish and wildlife. In the absence of market prices, the value of sport fishing, hunting, and other specific recreational forms of fish and wildlife may be derived or established in the same manner as [that described for recreation benefits above]. Resource preservation includes the intangible value of improvement of habitat and environment for wildlife and the preservation of rare species. Benefits also result from the increase in market value of commercial fish and wildlife less the associated costs.

(Reference 25, pp. 9-11.) [Emphasis added.]

Probably the most recent development in water-resource activity at the Federal level of government that directly affects water quality is the passage of Public Law 89-234, the "Water Quality Act of 1965" (123). This Act provided for the establishment of a Federal Water Pollution

Control Administration, which would function within the Department of Health, Education, and Welfare, although it was later placed in the Department of Interior through executive order. The Act further authorized 1) grants for research and development in the area of reducing discharges to streams from combined sewer systems, 2) grants for the construction of waste treatment plants, and 3) increased grants for urban planning. Perhaps the most significant part of this legislation was the provision requiring each state to adopt, before June 30, 1967, 1) water quality criteria applicable to interstate waters or portions thereof within its own state, and 2) a plan for implementing and enforcing these criteria. The criteria adopted by the states, if approved by the Secretary of the Interior, shall, according to the Act, become the water quality standards applicable to such waters. Furthermore, if the states do not comply in this regard before the date appointed, the Secretary is authorized by the Act to promulgate such standards. There are also provisions in the Act for the establishment of a Hearing Board to preside over hearings concerned either with possible adjustments of the standards or with violations of the standards.

The passage of this Act in 1965 presents a remarkable contrast to the Federal views on water quality expressed only fifteen years earlier by the Federal Inter-Agency River Basin Committee. Quite obviously the Federal government has placed the preservation and enhancement of water quality on at least an equal basis with navigation, power production, and other benefits to be derived from water as it occurs in nature.

A noteworthy feature of the economic policies of the United States regarding water quality, which have been reviewed here, is that the worth of such quality is forced to monetary terms for expression. Unfortunately this may lead to the conclusion that water quality has value only equal to the cost of improvement of water quality and minimizes or even neglects benefits to be derived from water once its quality has been improved to a desired level. We should look now more specifically at the benefits and costs involved with water quality for different users and how each might be evaluated.

Costs and Benefits

If waste treatment can be regarded as a separate industry, it is a unique one. It is one of few and perhaps the only one that produces a product that reaps economic gains for everyone but the industry itself. There are, of course, treatment processes employed to reclaim a certain fraction of the materials in some industrial waste streams, but if we regard "waste" as that portion of the flow that is ultimately to be discarded because it is no longer usable or profitable on the site, any treatment of waste costs money that is not directly recoverable by the waster from customers or society as a whole. This puts waste treatment in a different light than other economic enterprises, and is in large measure responsible for the lag of waste treatment practices behind those of water treatment and indeed most other private or public ventures where money is involved. It is also the main reason why government has taken a greater share of the money burden for waste treatment on itself and become more directly

involved in promoting waste treatment over the years. In any event it is to be noticed in the discussions below that water quality "benefits" are those that accrue to subsequent users of the treated waste, while water quality "costs" are those imposed on the waste discharger.

Benefits. As was noted earlier the Green Book and Senate Document 97 specify definitions of particular benefits and costs involved with implementing and evaluating Federal water-resource projects. For our purposes here we will talk about three types of these benefits. The names used here are the same as some of those in the Federal policy statements and these terms will mean very nearly the same things when applied to waste treatment.

Primary benefits, then, are those benefits that result directly from the removal of some constituent of the waste flow at a proposed treatment plant and that are measurable in monetary terms. Secondary benefits are those that accrue indirectly as a result of the removal and which may be measurable wholly or in part in monetary terms, but which do accrue through a market transaction. Any benefit that is not reaped in a monetary fashion will be termed an intangible benefit; however, this does not imply that a dollar value cannot or will not be imputed to as much of this benefit as possible for purposes of analysis.

As an example, the removal of BOD from a domestic sewage discharged to a stream may improve or preserve commercial and sport fishing in downstream areas by allowing dissolved oxygen levels to remain high throughout the reaches populated by fish. Increased profit

of the commercial fishermen and increased expenditures by sport fishermen to avail themselves of the opportunity to fish in this stream would be primary benefits of removing the BOD. If the commercial fisherman can buy more boats, nets, or other equipment with which to catch more fish, as a result of making more money because the BOD load was decreased, his still further increased fish sales would be secondary benefits. Likewise, increased tourism and fishing expenditures in the area by sport fishermen resulting from the original BOD removal and subsequent enhancement of the fish environment would accrue as secondary benefits. Increases in relaxation and enjoyment and perhaps esthetic improvements such as removal of odors that once occurred as a consequence of the higher BOD load would be included in the total benefits as intangibles.

Benefits that accrue as a result of waste treatment can best be studied and allocated by dividing these benefits among the users to whom they obtain.

Water Supply.--Both municipal and industrial water supplies are protected in some measure by upstream waste treatment. Although, as Frankel (39) has pointed out, the benefits to downstream water treaters from upstream waste treatment are negligible to very small, nonetheless benefits are realized and their amounts depend on many things. The value of these benefits can be derived from increased costs at the water treatment plant that would be necessary if constituents of importance were not removed upstream. These foregone costs include those of additional chemicals, power, labor, land, or other

materials that would be necessary to continue producing water of the same or requisite quality as before the influx of the upstream waste discharge.

The amount of these benefits, that is, foregone costs, depends on 1) streamflow and its associated probability of recurrence, 2) the size of the upstream waste treatment operation, 3) the degree of removal of each of the pertinent constituents at the waste treatment plant, 4) background quality of the stream with respect to the constituents of importance, 5) associated stream and waste characteristics, 6) the time of travel from the waste treatment plant to the water treatment plant downstream, and 7) the type and size of the downstream water treatment plant (39).

Benefits to downstream water treatment plants are probably most often primary benefits, that is, they are usually foregone costs of increased treatment and are measurable in monetary terms. If, however, rather extensive treatment improvements would result as a consequence of the upstream discharge, and if it would become necessary to hire a more skilled technician or supervisor to operate the plant, the increased salary expense foregone might be classified as a secondary benefit. Intangible benefits derived from preserved smoothness of operation at the downstream water treatment plant are difficult to enumerate, much less evaluate, since these things depend so heavily on the individual situation. They probably do exist in virtually every case, however, and should be included if at all possible. It seems intuitively to be true that waste treatment that prevents a downstream population from having to become involved with increased bonding or

taxing or further hiring or construction to preserve the integrity of its water supply has rendered that population a favor that is perhaps inestimable but surely a positive and significant benefit.

Irrigation.--Benefits of irrigation water are logically evaluated as increased profits from the sale of irrigated crops that result from the use of the irrigation water as compared to sales before irrigation was used or in lieu of irrigation altogether. These increases in productivity are relatively easy to evaluate if the question is one of irrigation water quantity. It becomes more difficult to account for increases in profit that result or might result from improved quality of irrigation water. This is because the quality constituents that affect productivity often take several seasons to make their effects felt. As an example, high sodium content may not cause the soil to harden and hence to obviate proper infiltration for several or even many years after the original increase in sodium content occurs. The toxic effects of boron, on the other hand, may become evident rather quickly, depending, of course, on the concentration of this toxicant in the irrigation water and the intensity of the irrigation program.

Nonetheless primary benefits of increased sales of irrigated crops will accrue as a result of upstream treatment if constituents of importance to the irrigator are inherent in the waste and are removed. Furthermore if these net increases allow the farmer to procure more equipment, fertilizers, or labor that in turn increase his income, these secondary net gains should be counted as secondary benefits of

the removal of those critical constituents. Intangibles might result either in the form of redder, juicier apples or simply as increases in the general standard of living.

Recreation.--There are numerous and varied benefits that accrue to people having fun, almost all of which are not of the dollar-and-cents variety. Benefits resulting from improved water quality cannot all be counted "in the water," either; the recreation experience on land, but near water, can be enriched by quality improvement also. Thus Senate Document 97 (95) includes as recreational benefits net increases in both quantity and quality of boating, swimming, camping, picnicking, winter sports, hiking, horseback riding, sightseeing, and similar outdoor activities.

These opportunities for good times, it should be remembered, were listed as possible benefits that would result from the construction of a water resources project. In general this would usually mean the emergence of a new reservoir that would attract both relaxing people and concessionaires to supply these water-loving people with ancillary modes of release, camaraderie, sport, and communion with nature. Thus the expenditures that the added number of fun-lovers and naturalists would make at the new recreational site are a reasonably good measure of the primary benefits that accrue to the project in the recreational wedge of the project pie.

Evaluation of strictly quality benefits is not quite so straight forward. Furthermore it is possible but only remotely so that all of the outdoor activities listed above would be demonstrably

affected by upstream waste treatment. It might be difficult, for example, to show a relationship between degradation of water quality and a concomitant drop in horseback riding and especially in profits to be made by the barn manager. Nonetheless it is possible that extreme quality degradation could result in downstream areas being abandoned as recreational sites, and in such instances all decreased profits in the recreational sphere that could be prevented by waste treatment upstream should be counted as primary benefits.

Because even this measurement of primary recreational benefits is such a difficult and time-consuming task, the public's "willingness to pay" (95) for its enjoyment has been estimated by counting the number of visitor-days spent at a site and multiplying this number by the entrance fee charged (110) or some estimated amount that is spent to get to the site and to enjoy what it has to offer (106). Secondary benefits (fees charged to view resulting home and promotional movies?) and intangible values have been ignored traditionally or else tacitly included in the one multiplication operation just mentioned. No one has denied or ignored the fact that the whole idea of recreation is to derive pleasure or "benefit" of an intangible kind, but methods of analysis have not been advanced to the point of including these gains quantitatively.

Fish and Wildlife.--A tramway to carry fish in buckets over a dam in the western United States was built at a cost of 1.5 million dollars. In the first year of operation 1300 fish were transported over the dam (17). If, in 100 years and at 4 percent interest, the

tramway is to pay for itself, someone is going to have to "benefit" \$47 worth for each fish transported. Although it is not likely that this will happen in a strictly market way, the example illustrates the amount of money that is being spent to derive fish and wildlife benefits.

Primary benefits from fish and wildlife preservation are easiest to measure or estimate if the fishing potential in the area is commercial. Here increased market value of the fish caught less any associated increased costs becomes the benefit of the project. Senate Document 97 (95) points out, however, that the increased value of sport fishing, hunting, or other aspects of fish and wildlife preservation should also be included as benefits; although they are likely to be intangible, at least in part. If estimates can be made of increases or foregone decreases in expenditures for hunting and fishing equipment, licenses, and travel as a result of improved hunting and/or fishing potential stemming from improvements in or maintenance of water quality, these expenditures should be counted as primary benefits of waste treatment.

There are benefits that accrue, as will be pointed out in detail later, for improving or maintaining the levels of many individual quality constituents. For the sport fisherman perhaps all of these benefits are of an intangible nature and may not be very large, per constituent. For example, the fisherman may not even be aware of the dissolved oxygen content of his favorite trout stream, and as long as he is able to catch fish there he will buy his license, his picnic lunch, and his rod and reel to go there and enjoy himself. He expects, however,

that the fish will be there the next time he comes to fish some more. Consequently the stream must remain a suitable environment over a long and continuous period, regardless of the sport fishermen's "visitor-days" on the stream bank and regardless of his one-time per year expenditure for a license. There is a disparity, then, between the parties who really benefit from upstream waste treatment where fish and wildlife benefits are concerned. Is it the fish or is it the fisherman?

Although benefits of fish and wildlife preservation are normally evaluated by considering the amount of money that sportsmen are willing to spend to enjoy the out-of-doors, increasing concern in policy statements and discussions of water quality law (21) (95) (104) (122) has been given to assuring the wildlife itself a suitable and even pleasing habitat. Apparently it is left to the engineer-planner to convert hazards to fish into displeasure for a sportsman and thence into dollars. It is clear, however, that the fish and other animals, and particularly rare species, are to be granted certain water rights, their nonexistent buying power notwithstanding (95). These benefits, which are perhaps entirely intangible, are assumed to accrue to society as a whole. Even if anglers do not presently fish a stream that contains sport fish, it is to the "benefit" of the society to be able to point with pride to a place where they might do so if the mood strikes and their increasing leisure allows.

Other Uses.--Under certain circumstances there may be quality benefits that can be realized by other users of water than those mentioned above. Navigation, power production, flood control, land

stabilization, and drainage benefits are listed in Senate Document 97 as legitimate users of water and benefiterers from water projects (95). As "other benefits" the Document mentions net economic effects of changes in transportation capability or changes in productivity of forest, range, mineral, or other resources, as well as contributions of a project toward serving the interests of international treaties or national defense.

If water quality benefits for these or still other uses of downstream water will accrue as a result of waste treatment upstream, they should be included as justification for the plant.

Costs. It is difficult to speak in general terms about the costs associated with waste treatment. Construction and operation costs of waste treatment plants depend on innumerable things. Among these, however, are the size of the plant (or the population to be served), the degree of removal necessary for each constituent of importance, the composition of the raw waste, the complexity of operation of the processes adopted, and general economic factors of time, location, and associated price-level changes.

Some generalizations have been made about waste treatment costs, however, in an attempt to learn how costs vary with size and population served (79)(100)(101)(121). In addition to these studies there are some recent data available that include estimated costs for tertiary treatment processes that are not yet used very widely (3)(92)(105). In addition, the work of Frankel (39) has contributed a large amount of cost data of a more specific nature than has probably ever

been reported previously. With data from many sources throughout this country, he has reviewed and compared the costs of numerous and varying types and degrees of treatment, from chlorination alone through several modes of tertiary treatment (39).

With all these data available, this writer has arrived at the generalized curves shown here as Figures 1 and 2. These curves are hardly gospel truths and are not presented as guides for cost estimation. In spite of the rather large amounts of data that have been gathered by the above-mentioned authors and the innumerable other authors who have published articles on the design, construction, and associated costs of individual plants throughout the country, we cannot draw firm conclusions from these in an exact way. Nonetheless, two general conclusions do seem valid: 1) the larger the plant required, the lower will be the unit price of treatment, and 2) the more things we try to remove from wastes, and/or the more of a given constituent we try to remove, the higher the cost will become.

There is still no clear way available to separate the cost of BOD removal from that of suspended solids removal or from that of any other constituent. Furthermore we know that secondary biological treatment will remove, besides BOD and suspended solids, some fraction of the nutrients, heavy metals, and other materials present; the separable costs of these removals still elude us, and we are forced to accept these removals simply as "gravy." Frankel (39) points out that it is unreasonable even to try to separate these costs. In Figure 2, the dotted curve is shown differently from the others because there

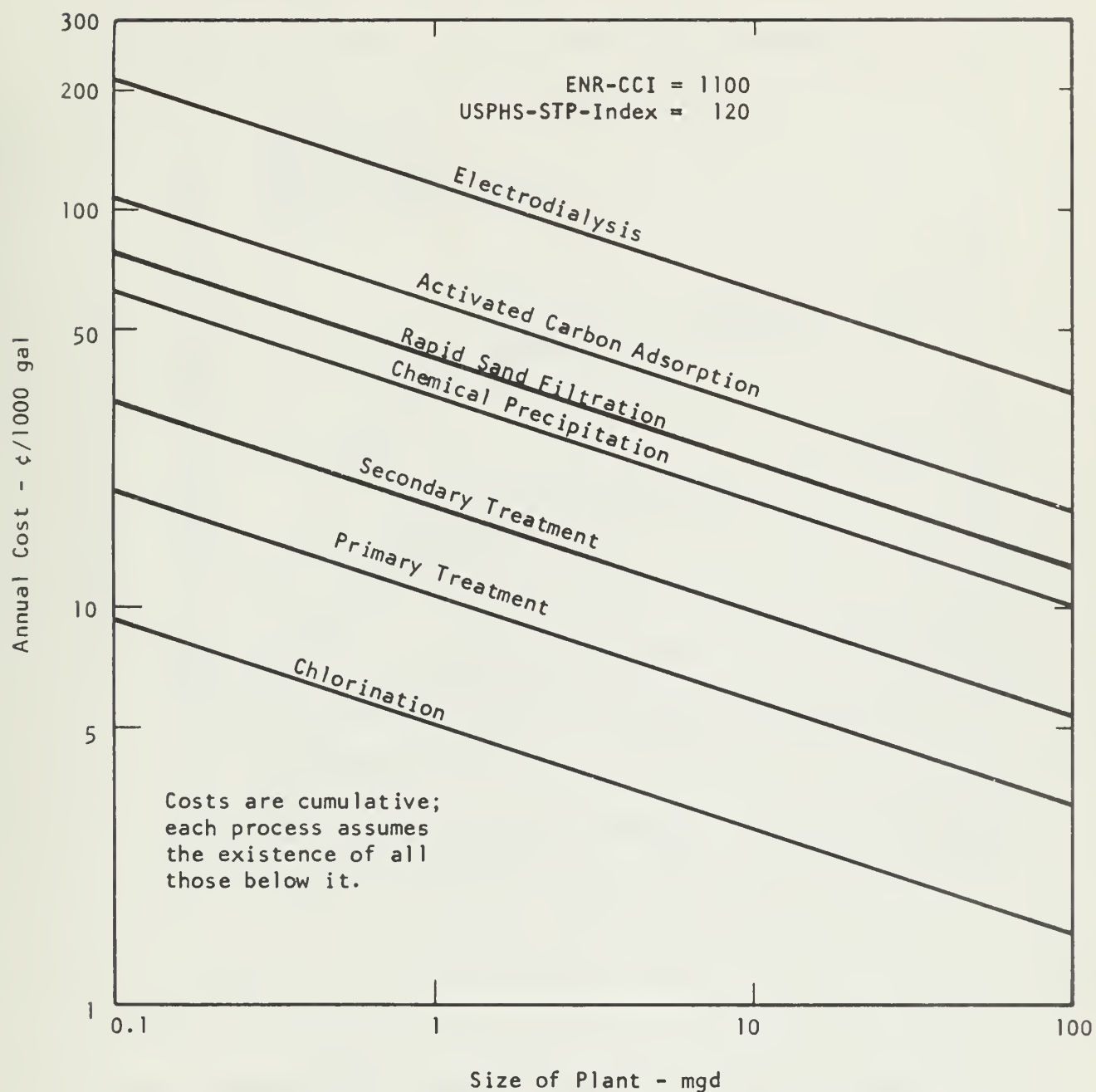


FIGURE 1. ECONOMY OF SCALE FOR SEVERAL TREATMENT PROCESSES

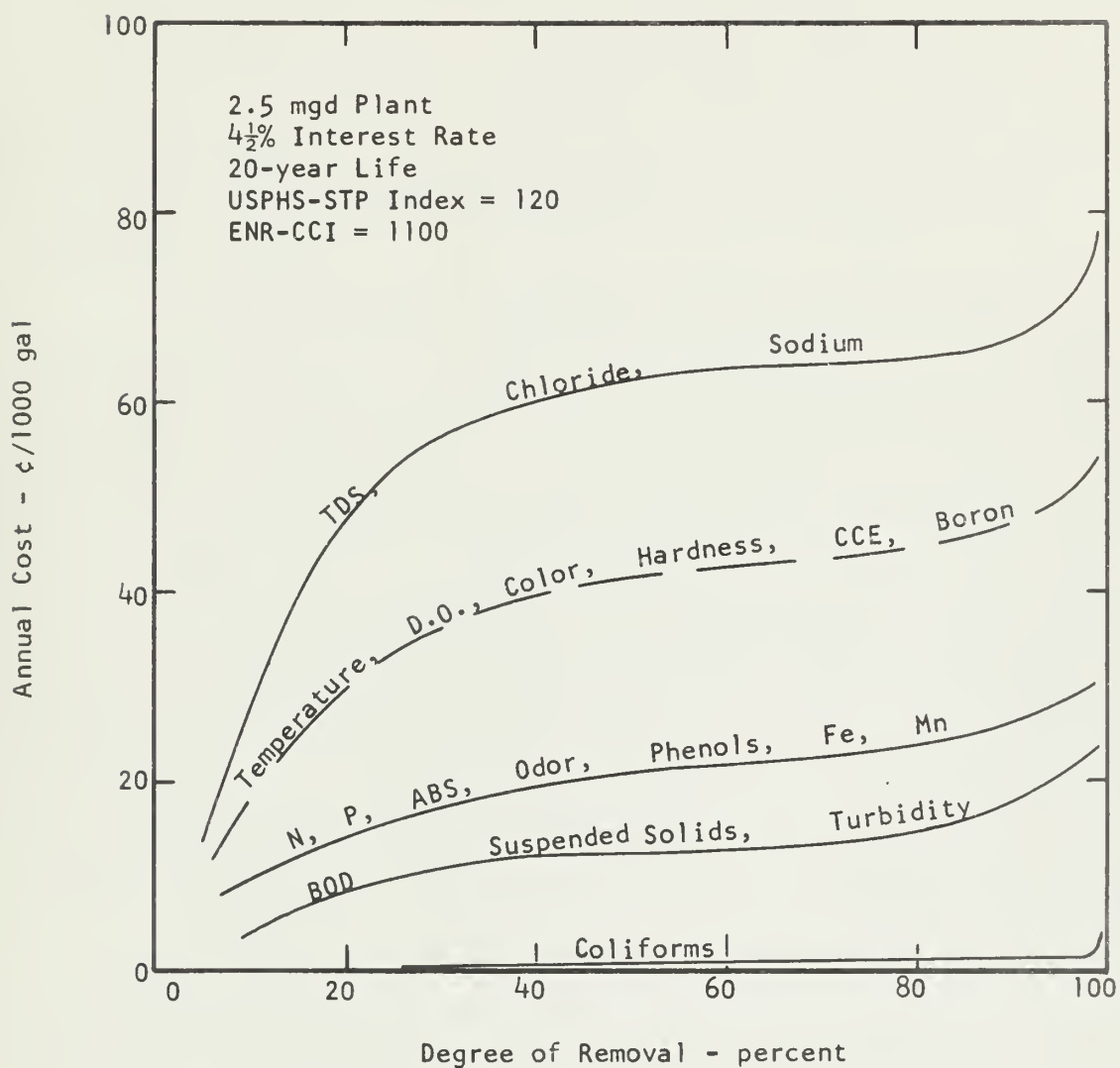


FIGURE 2. REPRESENTATIVE COSTS OF IMPROVING THE QUALITY OF WASTE WATERS

were no data available on which to base this curve. Since in the near future we probably will become more concerned in waste treatment with the constituents shown on that curve, the curve was included. It was done strictly by inference from Figure 1 and on the basis that it must fall in the region somewhere between secondary treatment and electrodialysis.

The curves show an ordinate of annual cost in ¢/1000 gallons. What is that exactly? It is the sum of the capitalized first costs and annual operating expenses. First costs include land, construction, and design costs. Operating expenses include chemical, power, and salary expenses, as well as upkeep and replacement costs. To bring the data of the several sources to a common, and therefore comparable, place in time an Engineering News-Record Construction Cost Index of 1100 or a U. S. Public Health Service Sewage Treatment Plant Construction Cost Index of 120 was used (2)(18)(120)(121). These values were projected by the writer to obtain simultaneously on or about January 1, 1967.

It should be pointed out again that individual cases checked against these two curves will result in the costs of particular plants being both higher and lower than the costs shown here. These curves are included merely to demonstrate economy of scale, increased costs of more thorough treatment, and only generally what it may cost to treat a waste. It should also not be concluded that the constituents shown on Figure 2 are the only ones of possible concern. Furthermore it should be mentioned that in water resources parlance these costs correspond closely to "primary" costs. There are also such things as secondary

and intangible costs. For example, costs associated with solving a resultant odor problem at a waste treatment plant are secondary costs, while the odor itself lingering throughout the neighborhood is an intangible cost that must be borne by the community, at least until the problem is solved. However, throughout this thesis such costs will be assumed to be incorporated either in operating costs or as a benefit to be gained through prior avoidance of such costs. Traditionally they have apparently been included with operating costs or ignored.

In addition to the presentation of cost data, some philosophy should be discussed as well. Several authors have expressed concern, which is apparently widespread throughout the engineering profession, that the cost of sewage treatment must be kept to an absolute minimum lest the nation be faced with "an inexcusable, perhaps intolerable burden on our country's economic growth and its ability to compete in tomorrow's world" (85) (131). Others have stated that pollution control costs, which must ultimately be visited on the public who benefits from them, should be kept in proper perspective with other social needs and desires (6) (7) (62). Just what is the position of water and waste costs relative to other social needs and desires?

Fair, Geyer, and Okun (36) indicate that water costs between 5 and 50 cents per 1000 gallons and that sewage disposal and treatment costs are about the same. These costs include both distribution systems and treatment facilities. For strictly metabolic purposes man's intake of water is about 2.2 liters per day (107). Consequently, he needs--

really needs--about 212 gallons per year. If we assume the higher rate of \$1.00 per 1000 gallons prevails for both bringing good water to him and disposing of what is left, this man can earn these services for a full year by working for about 10 minutes at the prevailing minimum wage in this country.

But we know that man wants and "needs" much more than a half gallon of water per day. Taking industrial use out of the picture for the moment, let us assume that each member of a residential household uses 60 gallons per day. At \$1.00 per 1000 gallons for both delivery and disposal this costs about \$22 per year per capita.

Opposed to this, it costs society \$564 per pupil per year to educate our children in elementary and secondary schools; it costs society \$2690 to keep one person in prison for one year; it costs society \$1800 to maintain a mother and three children on relief for one year (14) (90). If we washed our cars ourselves at home with the water supplied and discarded municipally at \$1.00 per 1000 gallons, it would cost about 60 times less than we are willing to pay at the local "minute-wash." We can buy about an ounce of reasonably good Scotch whiskey for the same price we pay for 1000 gallons of water. We can get about one gallon of milk for about the same price, or about three gallons of gasoline. Twenty-two dollars might buy one reasonably nice clothing outfit for a teenager, maybe two books for the public library, and perhaps four tickets to a Broadway play. That is about where present combined water and waste costs fit. There are those who say that the public is willing to pay more for these services, but that

the utilities themselves have traditionally promoted lower costs for fear of losing customers (53) (83).

Brandt (13), among countless others, has warned that dumping industrial wastes into a water course may well be a more economic use of the stream than is sport fishing, and that emotional cries for the protection of a minority should not be allowed to overshadow this economic fact. He warns, moreover, that engineers should beware of their traditional urge to immediately assign municipal drinking water an exorbitantly higher priority than industrial water, when in fact industry often uses and buys much more water than the surrounding residents.

In the face of the old argument that waste treatment costs will force industry to move away or completely shut down, an encouraging counter point has finally been made. A recent article (4) has pointed out that the management of one large chemical industry has been made to see that spending the necessary funds for adequate waste treatment, and recovery where possible, actually leads to maximum profits, and not bankruptcy at all. This results from increased labor efficiency and lower maintenance costs within the plant and reduced liability claims from without. The same article points out that although pollution control expenditures for industry are large, they are usually less than 5 percent of total capital investments and between 0.5 and 1.5 percent of companies' total operating expenses (4). This includes both air and water pollution prevention measures.

"Economic development enables us to pay the price; it is why we have development. We do not have development in order to make our

surroundings more hideous, our culture more meretricious or our lives less complete" (44).

Benefit-Cost Ratios

The benefit-cost method of analysis for evaluating alternative courses of action dates from the turn of the century and originated with the Army Corps of Engineers (92). Its underlying philosophy has been that the project among several which has the highest ratio of total annual benefits to total annual costs is, from among the alternatives, the one that should be constructed; provided, of course, that the ratio for this particular project is greater than 1.0. If benefits do not exceed costs, that is the ratio is less than 1.0, the project is not economically justified. This method of analysis has been used in this country primarily to evaluate water-resource and transportation alternatives (70). It has been used where water quality is concerned only in a limited way: to evaluate the water quality benefits of low-flow augmentation, for example (70). However, Senate Document 97 (95), as well as other sources (29)(127), indicates that it will be used more and more widely.

Prest and Turvey (96) have provided a rather thorough survey of the benefit-cost method of analysis and its strengths and weaknesses. Some of their findings will be reviewed here.

First of all, the technique is limited both in principle and in practice. In principle it should be understood to be a technique for making decisions within a predetermined policy framework and it is limited by this policy, which encompasses considerations of diverse

types including those of a social and political kind. The use of the benefit-cost ratio method for evaluating alternatives is not the policy itself; it is only a tool to help implement the policy; the economic objectives must be chosen beforehand. Secondly the technique is not adequate to handle very large-size projects that could of themselves cause alteration of the price system throughout the entire economy. Whereas these conditions are hardly likely to obtain for water quality projects being planned in this country, nonetheless they might arise in some of the developing nations. Prest and Turvey (96) point out that even in such cases as those the technique may not fail completely, but the manipulators of the method should stay more acutely aware that this limitation exists.

Brandt (13) rather succinctly criticized the technique's main weaknesses when he said that considering projects yielding a benefit-cost ratio of greater than 1.0 and then choosing the one with the highest value from among the alternatives not only invites "over-estimation of benefits and underestimation of costs, but it provides no sensible criterion for a comparison of many projects as to their contribution to the growth of the social product." This last assertion is another way of saying that the technique does not encompass the entire policy objective for considering the development of the project in the first place. Having a benefit-cost ratio calculated for each of the alternatives does not end the search for which of these should be undertaken. The remainder of the priority rating, indeed the choice itself, must be left to the public, its representatives, or industrial management, whoever is involved and by whomever the engineer is employed.

It is, of course, of vital concern to whoever is left to make the choice that an economic analysis of this sort be made, but there may be facts or attitudes available to these policy makers that will lead them to choose from among the alternative solutions one that does not have the highest benefit-cost ratio but that will at the same time best meet their objective.

There is also apparently some tendency for analysts to sanctify the number 1.0 (13) (96). Planners interested in the building of dams, canals, or other water projects, while conscientiously trying to be objective in their evaluations, may be eyeing the cost column while enumerating and evaluating the benefits. In private conversation with the writer some water planners and hydrologists have admitted that if a benefit-cost ratio for a project turns out to be 0.9 or as low as 0.7, they will sometimes repeat the calculations to see if something was overlooked or left out. Sometimes benefits are recalculated, other times the design flood computations are checked to see if the predicted event could really be so large. This philosophy is not altogether to be condemned, particularly considering the many rather hazy estimates that must be made. It is an interesting observation, however, that projects whose benefit-cost ratio is reported, usually have a calculated ratio of 1.2, 1.5, 1.7, or some similar value. It may be reasonably factual that these are the values, but never has this writer found a reported benefit-cost ratio of 65, 317, or anything nearly so convincing. Still many projects must be clearly justifiable. On the other hand it is likely that some projects have been undertaken that had a calculated benefit-cost ratio of greater than

1.0, but which value must have stretched the resourcefulness of the planner to have been obtained.

Just the enumeration of costs and benefits presents problems, even before we begin to evaluate them. The definition of the project itself, the project life, and any externalities or secondary benefits that are to be included are all decisions that are not easily made, but that must be made before the analysis can be completed (96). Usually the scope and nature of the project will be clear, but occasionally there is overlap between the proposed project and others belonging to or controlled by the same authority. For example, if the project to be evaluated is a dam, its existence may affect water levels, power outputs, and other factors at downstream dams operated by the same authority. It may or may not be that these effects at the downstream dams are part of the proposed project, and hence the costs and benefits accruing there should or should not be included in evaluating the new project, depending on a policy decision that must be made first.

Externalities are perhaps the central problem of waste treatment evaluation. In almost every case the benefits of waste treatment fall to people or institutions outside the baliwick of the people or institutions that provide this treatment. This reaping of benefits by people other than those who make the investment is called an externality, and much has been written lately (12) (66) (69) (70) (130) about proposed procedures for "internalizing" these effects. In essence the procedures would call for the organization of an authority that has jurisdiction over a wide enough area to include both the spenders and the benefiteres such that the benefiteres will be made to pay part of the price of having

their water quality interests protected. Economically this would be a much neater arrangement, but only one or two such authorities exist today, and the problem of dealing with externalities in benefit-cost analyses remains with us.

Generally speaking there is one overall distinction to be made about the inclusion of benefits as externalities. They should be included if they are alterations of "the physical production possibilities of other producers or the satisfactions that consumers can get from given resources (96)" as a result of the project. They should not be included if they are merely benefits that resulted from prices going up, even if the project in some way led to this price change. Part of the benefit of a project might be from flood control, but although land value protection would be a sub-part of this primary benefit, it would be double counting to include the increased value of land resulting from increased rent rates, even if the project caused rents to go up. This side effect might properly be included only once as a secondary benefit or not at all, depending on whether or not it can be concluded that this price change was indeed caused directly by the project itself, and whether this increase could not have been reflected in the market system by any other method than by imputing a value to it based on assumed rent increases, and whether the reaping of this sort of benefit was one of the project objectives. All three conditions must hold or the rent increase value should not be included. Prest and Turvey (96) have said, "...we are concerned with the value of the increment of output arising from a given investment and not with the increment in value of existing assets." They have also pointed out that this is not a simple distinction to make, and that

there seems to be some inclination for side effects to be included (double counting) more often when similar organizations are involved. For example a local authority seems to have a greater compulsion to account for costs it imposes on other local authorities downstream than it has for masses of individuals (96).

Secondary benefit evaluation is another area where double counting can occur. The distinction to be remembered here, which is not a simple one to make in many cases, is whether market prices already reflect the marginal social benefits or costs that we think will result from the project, in which case they should not be included; or whether the market has no way of including the benefits from the particular output of the project being considered, in which case these benefits should be included. For example, the benefits from irrigation water can be evaluated, for a wheat farmer, as the price he is able to get for his wheat plus the secondary benefit to be derived from selling still more wheat than his first profits allowed him to grow because he could then buy another tractor, minus his costs for the irrigation water and the tractor. The secondary benefits are his extra wheat sales less the cost of his tractor and not the extra bread sales minus milling and baking costs and the cost of the tractor. The market demand for wheat already reflects the value of extra bread and the costs of milling and baking. It does not reflect the value of the water itself and the benefits to be gained therefrom, and so these values alone must be imputed (96).

We will have more to say later about the particular problem of time in an economic analysis, but it has relevance to the enumeration problem of benefit-cost analyses. Project life, as we shall see, depends on many things, is often a rather subjective decision, and the error that a wrong choice would manifest depends on the interest rate adopted; the larger the interest rate, the less the effect. It is obviously another policy decision that must be made outside of the benefit-cost analysis itself, although it has direct bearing on the outcome.

So much for enumeration problems, which are formidable. Evaluation problems are at least as troublesome, but they are more obvious, and hence require less discussion. Perhaps the most obvious one is that some users or benefiterers can only have the value of their benefits estimated through the alternative-cost method, whereas benefits for others can be estimated or measured directly, but perhaps only incompletely. The question arises whether the benefits for both users estimated two ways are really in their true relation to one another. One can only hope and pray that they are, or seek solace in the knowledge that they are, "to the best of his judgment."

The other truly difficult problem is the one of assigning intangible values. Prest and Turvey (96) have written that these values must be included in the prose of the analysis since there is no way to include them in the arithmetic. In the method to be derived here we are going to attempt the inclusion of intangibles within the arithmetic, but we may as well begin admitting now that it will only imperfectly be done.

Other problems requiring considerable judgments of evaluation include the measurement of utility in general and the comparability of utility among different users, allowances for market imperfections and externalities which can only be imperfectly known, the choice of an appropriate discount rate, and wrestling with socio-economic uncertainties such as major political or military upheavals or natural disasters, which Prest and Turvey correctly point out (96), "none of us can predict...."

Faced with all of these weaknesses why do we persist in using this technique? First of all, and very simply, there is nothing better available. Secondly, it forces those responsible to quantify benefits and costs as well as can be done, rather than resting on vague qualitative judgments or personal hunches. This, Prest and Turvey have said (96), "is obviously a good thing in itself; some information is always better than none." Thirdly this technique does lead us to some understanding or knowledge of the prices that consumers are willing to pay, and it may cause questions to be raised about existing pricing policies and other soul-searchers that might otherwise never be questioned. Then too, "Even if [the] analysis cannot give the right answers, it can sometimes play the purely negative role of screening projects and rejecting those answers which are obviously less promising" (96). And finally, "...insistence on cost-benefit analysis can help in rejection of inferior projects, which are nevertheless promoted for empire-building or pork-barrel reasons" (96).

Optimization, Efficiency, and Minimization of Cost

Engineers have traditionally been forced to absorb concepts from fields other than their technologically narrow own, but it is likely that there is no topic more confusing or confused for engineers than the one we are about to discuss. The reader's particular attention is begged here, then, because apparently there is no simple way to make these concepts crystal clear, much less discernible one from the other. This problem has apparently led to confusion in the existing literature as well. Hopefully the concepts pertinent to waste treatment evaluation can be gleaned from these sources, though, and their salient features distinguished.

The problem we face here is how to select a treatment process from among alternatives on the basis of the available economic data alone. Emphasis is given to an economic choice, since, as has been pointed out before, economic analysis will not necessarily lead to choice of the truly superior alternative in light of all the relevant objectives. Nonetheless there are certain purely economic objectives, one of which must be chosen by somebody. If it is not the engineer's choice to make, he must still know what the objective is to be so that his calculations will include at least one alternative that meets it.

The problem of objectives is this: authors have said at one time or another that the objective of waste treatment is to 1) find the alternative having the least cost (85) (131), 2) maximize the benefit-cost ratio (46), 3) maximize net benefits (benefits minus costs) (95) (97), 4) build only what is "absolutely necessary" and then build so that each increment of benefit is the maximum to be obtained

for the increment of cost (7), or simply to choose the alternative that is most economically "efficient" (71) or the one that is "optimal" (11)(77)(84). All of these sound like commendable objectives. We would probably like to do all of these things at the same time. The problem is they are not all the same thing. To introduce the quandary, assume our alternatives are either to build a secondary treatment facility that would cost 10 units and give rise to 12 units of benefit or to build a tertiary treatment device that costs 44 units but would yield 50 units of benefit. It turns out that the secondary treatment alternative has the least cost and the greatest benefit-cost ratio, but the tertiary treatment process would yield more net benefits and be economically more efficient. Both processes have benefit-cost ratios greater than 1.0. So where are we left? We are left with a policy decision that may not be ours to make.

Figure 3 depicts the problem graphically and affords an easier way by which these concepts may be defined. In the first place, all of the terms introduced here are concepts or methods by which to choose how much project we should build or how big the project size should be. Should we build one big dam or three small ones; should we build primary, secondary, or some degree of tertiary treatment? In other words, given the benefits and costs that result from all the alternatives, what is the scale, the size, of the alternative to be chosen? Hence, Figure 3 shows a hypothetical set of cost and benefit curves plotted against the scale of development of many possible alternatives. It also shows the benefit-cost ratios that would

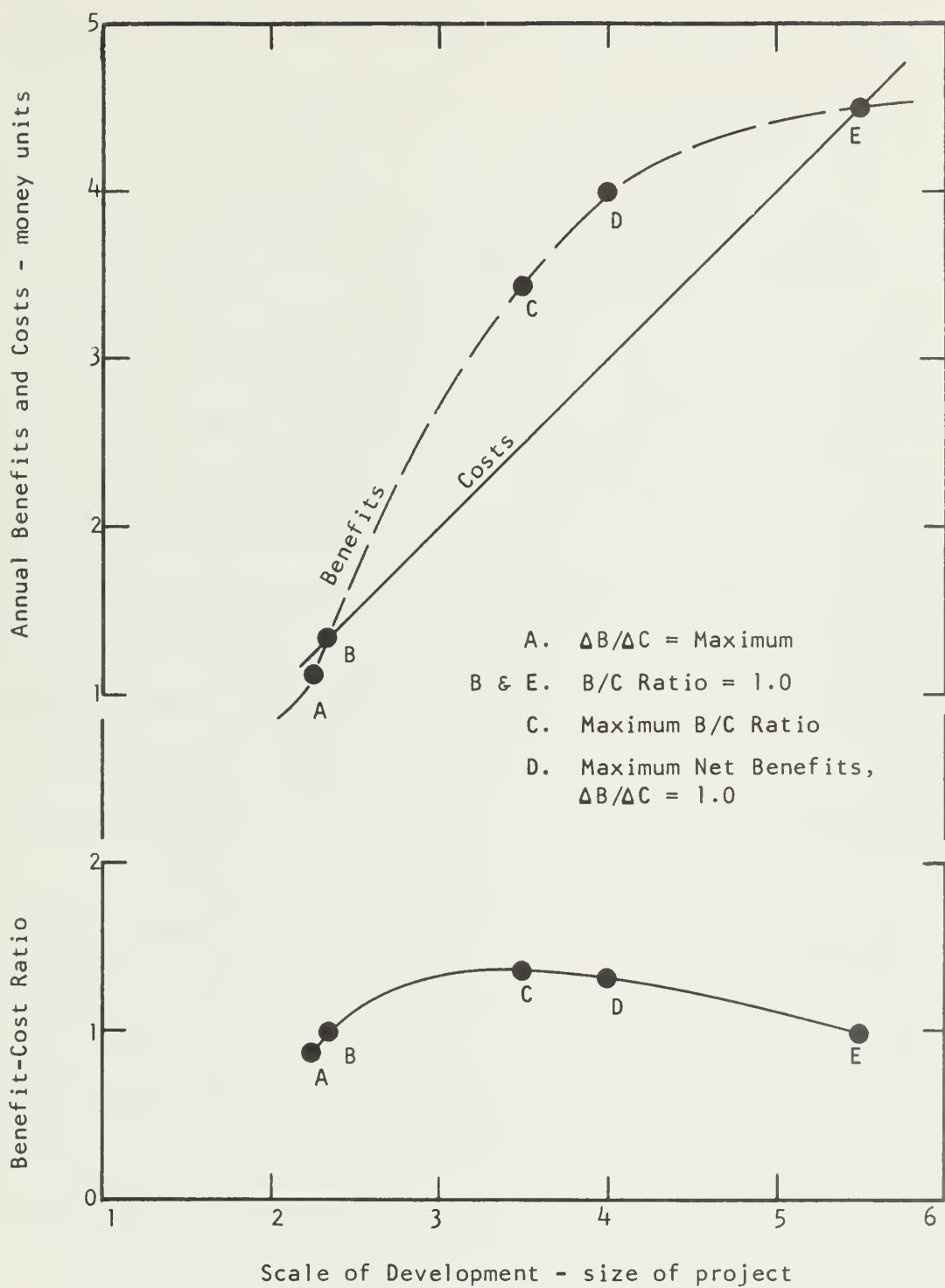


FIGURE 3. SEVERAL BENEFIT-COST CRITERIA

result for any scale of development. Similar curves may be found in several sources (29) (78) (97).

Points A through E are points at which the reported criteria are satisfied. A is really a special case which can be postponed for now. Points B and E are both indicative of scales of development that have benefit-cost ratios equal to unity. In terms of this criterion alone a Point-E project is equally as justifiable as one at Point B, and all the projects in between are also justified with respect to having greater benefits than costs. Point C represents the project size having the maximum benefit-cost ratio. Point D is the project whose net benefits are the maximum; that is, the difference between benefits and costs is greatest at this point. It is Point D that Senate Document 97 (95) calls the "optimum" scale of development. It should be noted, however, that the benefit-cost ratio at Point D is less than that of a range of projects to either side of Point C.

If a truly comprehensive discussion of this topic were possible, three points should be made right here, simultaneously; which is perhaps nonsequitur, but they are: 1) where does "efficiency" fit on the curve, 2) what is Point A, and 3) how can we use any of these concepts when almost always we are confronted with only several points on these curves (alternatives) that give us only a stepwise approximation of these smooth lines?

To answer all three questions in one sentence, Point A is a foul ball of the efficiency game, which can be played within the bounds of Points B and E, and which is played expressly for the purpose of evaluating one alternative against another, and hence really has no

one point on the curves. Efficiency is a game with complicated rules; at least they have been written in many versions that can lead to confusion. Krutilla and Eckstein (71) define efficiency this way: "...a situation in which productive resources are so allocated among alternative uses that any reshuffling from the pattern cannot improve an individual's position and still leave all the other individuals as well off as before." They restate this many ways, but what results is **that** for a given amount of money available for spending, the most efficient way to spend it is the way that will maximize the benefits from that expenditure. This does not mean at one point on the curve, though. It means that if a boy has a quarter and he wants to buy fishing worms and candy bars with that quarter, he will spend it in such a way that he will have amounts of bait and candy bars in relation to how badly he wanted each. It is making a dollar go not only a long way, but as far as it can go consistent with what we most want to have, then next want to have, and so on. It implies a ranking, then, of our preferences or willingness to pay for several alternatives. However, it further implies ability to answer the question that if we can only afford to have fishing worms or candy bars, which one would give us the most satisfaction or benefit. In still other words, that alternative among several stepwise alternatives is the most efficient that has added benefits over the others which are greater than the increased costs of netting these benefits.

In terms of the secondary vs tertiary treatment example, the increased benefits from building the tertiary process were 50-12, or 38 units; the increased costs to do so were 44-10, or 34 units. Thus the ratio of the net benefits and costs is 38/34, or 1.12, and hence the tertiary treatment alternative is more efficient than the secondary one. If the benefits of the tertiary treatment had been 51 units and the cost 50 units (still a benefit-cost ratio greater than 1.0), the efficiency test would yield a net benefit-cost ratio of 39/40, and the secondary treatment process would have been the more efficient investment to make.

What is Point A then? Baxter (7) has made the statement that it would be wise to pay heed to the old philosophy that we should build only what treatment processes are absolutely necessary and then do so in such a way that the amounts and the progressive additions of treatment "shall yield the largest results commensurate with the funds expended." This implies that we will climb up the benefit curve very slowly going no further, because of increased costs, than will maximize the benefits from each little cost step we take. In other words, the scale of development should be increased over time such that $\Delta B/\Delta C$ should be as great as possible. In Figure 3 $\Delta B/\Delta C$ is a maximum at Point A; that is, the greatest difference between the slope of the benefit curve and the slope of the cost curve occurs at Point A and decreases as the scale of development increases. It should be pointed out in fairness to Baxter that on the hypothetical curves shown in Figure 3 this happened to occur at a point where the benefit-cost

ratio is even less than 1.0, and that he probably did not mean to imply we would operate there. Indeed he was aware in the same article (7) that efficiency criteria might be used to allocate public expenditures among other social ventures than water pollution control, but that all of the alternatives to be considered should have benefits at least equal to their costs. If the boy cannot have both his candy bars and his bait for a quarter, then he might settle for a quarter's worth of one or the other; but if he cannot derive his full quarter's worth of enjoyment from either, he should not spend his quarter at all.

In terms of Figure 3, then, between Points B and D any larger project is more efficient economically than a smaller one; that is, although it will require spending more money for the larger project, the added benefits to be gained are greater than the extra expense. Between Points D and E, a larger project will be less efficient than a smaller project, because the benefits are now increasing more slowly than the costs.

But what of the least-cost criterion? Traditionally engineers designing waste treatment facilities have conducted a "feasibility" analysis that sought the least expensive alternative to meet the objective of "abating pollution." In some cases this objective has been as commendably stated as "to protect the downstream users" and sometimes was as limited as "to provide waste treatment," but in either case the objective usually was to be satisfied with biological waste treatment. Benefits, then, were tacitly assumed to exist and to accrue

as a result of providing this treatment measure, but they have rarely, if ever, been evaluated. Within our traditional philosophy there has been no need for their evaluation; we did not try to balance benefits against costs; the aim was to find out what each of several alternatives for providing treatment would cost and to select the least costly of these as the one to be built. Engineering economy texts (45) (47) teach this approach as the proper way to decide a course of action: to balance the costs against the returns and calculate the "break-even" point or to compute the annual costs of the alternatives and select the one that yields the lowest value. The unfortunate thing about this is that in those cases where these calculations do lead to the "best" answer, the benefits are hidden in the calculation as the "returns;" or they are constant, and hence the alternative meeting only the least-cost criterion does indeed become the one with the highest (most advantageous?) benefit-cost ratio.

We have assumed, then, that the benefits of waste treatment are always the same for a predetermined treatment facility like secondary biological treatment, which is only approximately true even at one location. But having assumed this to be true at the site being considered, we then calculated the costs of the required trickling filters or activated sludge facilities or of the different possible modes of activated sludge operation and arrived at the least-costly of these alternatives. If all the possible alternatives would deliver the same degree of treatment then our assumption about a constant value of ensuing benefits is very nearly correct. It would not have been correct to calculate the costs of providing primary

treatment and of providing secondary treatment and to assume that the less-costly of the two would automatically be the alternative to choose. Of course no one has ever made this mistake; everyone knows that primary treatment is not as good as secondary treatment, but that it is cheaper. It is so obvious, in fact, that it has only become a problem of academic interest in recent years.

These researchers (11) (28) (67) (77) (112) have attempted to show that there is a combination of different degrees of treatment, primary and secondary or secondary as opposed to low-flow augmentation, applied to a whole river or a certain reach of the river, that will maintain a certain quality level at least cost. If, for example, at all five cities along a stream only primary treatment were used, the dissolved oxygen level in the stream might become lower than the standard adopted, but this would be relatively cheap. If secondary treatment were used at all five cities, the standard could easily be met and even bettered, but the cost would be relatively high. Through systems analysis these workers have elegantly found the happy medium, which is to just meet the standard with a combination of treatment methods at, therefore, "least cost." To further complicate the whole picture, these workers have been led by the mathematical tools they employ to call this least-cost solution the "optimum" solution. This can easily be confused with the optimum condition defined by Senate Document 97 (95) as the scale of development at which net benefits over costs are maximized.

It should be made clear here that this basin-wide, least-cost solution is a far different thing from determining the least cost of

building one secondary treatment plant or one primary treatment plant, or, for that matter, of buying a car. Once the treatment plant and its inherent removal efficiency or the mode of transportation are chosen, we have fixed the benefits to be derived. Hence the least-cost solution is fully appropriate to evaluate the alternative construction and operation possibilities for the plant or the different available makes of automobiles in the same luxury range. In the basin-wide, least-cost solution, however, the costs of building a primary settling tank, of constructing aeration chambers, and of operating both are assumed to be minimized already; and the search now is for the combination of these minima that will give an overall minimum cost while just meeting a basin-wide, "standard" output. The use of the standard makes the overall basin benefits constant, but not the benefits to be derived from treatment at one location.

The procedure we are seeking here is still different. It must lead us to the decision for one individual whether to buy a bicycle, an automobile, or an airplane. Here, at one place, the costs and benefits are different. We cannot conclude straightaway that the bicycle should be bought because it is the least expensive of the alternatives. However, to be sensible and complete, we must evaluate the levels of satisfaction that we would require from each of the three and compare these to the least-costly models of the three vehicles that will provide the required performances. The carry-over of the analogy to primary, secondary, and tertiary treatment alternatives is fairly obvious. The big difference between deciding upon a vehicle for an individual and choosing a waste treatment process is, of course,

that the benefits all accrue to the spender in the former case, and the ponderous problem of externalities still remains in the latter.

Still we must choose the "levels of satisfaction" in any case. How do we do this? In 1964 Thomas (113) introduced in a formal way, to the water field anyway, the idea that water quality standards and benefit-cost ratios are inversely, mathematically, theoretically related. He said that to set a standard was automatically to impute a certain benefit-cost ratio. He showed, in effect, that

$$S = \frac{n C}{m B_p}, \quad (1)$$

where S is the standard, say 100 MPN/1000 ml of coliform organisms; C is the annual cost of treatment; B_p is the annual primary dollar benefits to be derived from meeting the standard; m is a factor to multiply times the dollar benefit to yield the total benefit, that is, to include the effects of secondary and intangible benefits; and n is simply a conversion factor to convert the benefit-cost ratio into the concentration units of the standard. He suggested, again in effect, that values of n could be found by measuring the other parameters from projects and standards that were in existence now, and that by this procedure we would then be able to decide with respect to future projects whether our standards of today were properly set or should be changed.

Thomas' article (113) was written in a humorous, tongue-in-cheek vein, and he fully recognized that to evaluate the necessary parameters to put this idea into practice might be nearly impossible.

Nonetheless, for those conditions where it might apply, and there are many where it will not, his theory is correct; it has been seconded (30) (134), and has never been assailed. It does warrant some discussion here.

Standards are another method of forcing the assumption that the total benefits of waste treatment are constant. If the quality of a river or aquifer can be maintained at some level defined by standards for the constituents of concern, and assuming that values of utility do not change downstream, then the benefits to be derived by the users of this water are indeed constant. Furthermore, maintenance of this quality standard over time implies that the costs of doing so, ignoring inflation for the moment, are also constant. Hence the standard should be related inversely or at least mathematically exactly to the resulting benefit-cost ratio.

However, and unfortunately, there are both practical and philosophical reasons why this approach cannot be realistically applied, either to the problem of setting standards, or, having the standards established, to the problem of calculating the cost of meeting it.

All the problems are ones of variability. Immediately there are the problems of risk and uncertainty that plague benefit-cost analyses already. But beyond these there are variabilities from place to place in hydrology, price level changes, social wants and needs, and costs (even least costs) of providing the same degrees of removal. A more formidable problem still is that Thomas' equation is only for one scale of development, and so it does not provide for variability in

benefit-cost ratios to achieve the same standard resulting from differing economies of scale.

There is, still further another ramification of the bicycle, car, airplane problem. If a new motorcycle or a used car costing about the same amount will both satisfy one individual's special needs about equally well, while most people still consider them quite different, at least one person's benefit-cost ratio will be the same for either of two very different standards. In waste treatment terms a bale of straw used as a strainer on a secondary clarifier effluent may decrease the effluent solids content markedly in terms of compliance with a newly-instituted water quality standard. However, there may be no one downstream to reap any extra benefits. Hence very nearly the same benefits and costs may prevail but two different standards have been met: the new one and the one the operator accepted before.

The greatest drawback to the applicability of Thomas' theory, though, is that in most cases benefit-cost ratios do not change very much with a change in the standard. We have already seen in the secondary vs tertiary treatment example that for the two very different degrees of removal obtained the benefit-cost ratios and related economic objectives were so nearly the same that the final choice was difficult to make. This is probably very nearly a general rule: if the standard is raised, both the benefits and the costs increase leaving the ratio very nearly the same. This is again true in the bicycle, car, airplane problem.

So our process of choosing levels of satisfaction remains separated from the economic analysis, although these levels do affect the outcome of the economics. We outline first what standards, professional or legal, we would like to meet. There may be one or several, and there may be several possible levels of the same one. Secondly and separately we must evaluate the benefits that would accrue from meeting each standard and the costs of doing so. From a comparison of these results hopefully the economically advantageous alternative will emerge.

Time and Interest Rates

The fundamental principles relating the values of money at different points in time are defined and explained in elementary economics texts (45) (47). Again the concern here is not with evaluating the various investment, amortization, and operating advantages of providing either circular or rectangular settling tanks. It will be assumed that these calculations have already been made. This work will be done in terms of annual costs and benefits of providing alternative types and degrees of treatment in cost units of cents per 1000 gallons. It should be made clear, however, how the values of annual cost were derived in these terms from the reported literature, which usually gives costs in terms of an initial investment in dollars and operating expenses in dollars per year.

The annual cost, AC , in cents per 1000 gallons of providing a treatment plant having a capacity, Q , in millions of gallons per day, a

first cost of FC in dollars, and operation and maintenance costs of OM in dollars per year can be computed by the relationship

$$AC = \frac{(FC \times crf) + OM}{Q} \times \frac{1 \text{ yr}}{365 \text{ days}} \times \frac{100\text{¢}}{10^3} \times \frac{10^6 \text{ gal}}{(1000 \text{ gal})} \quad (2)$$

or

$$AC = \frac{(FC \times crf) + OM}{Q} \times 2.74 \times 10^{-4}. \quad (3)$$

The constant, crf, is a capital recovery factor that converts the initial investment cost to an annual cost including the payment of interest. This is the factor that, for the purposes of this work, makes the ultimate connection between time and interest rate, and it is expressed by

$$crf = \frac{i(1+i)^n}{(1+i)^n - 1}, \quad (4)$$

where i is the interest rate per time period expressed as a decimal, and n is time in payment periods, usually years (47).

Frankel (39) has reported that sewage treatment plants generally have an expected life of 25 years or less. Water treatment plants, on the other hand, have a life expectancy of around 40 years. The reasons for the differences are 1) and most importantly, sewage plants cannot adjust to increases in load resulting from community growth as efficiently as water treatment plants can, 2) of the two types, obsolescence seems to overtake sewage treatment works faster, and 3) the variety of equipment in water plants tends to last longer than that of sewage

plant equipment (39). Frankel further indicates that interest rates of about 4 percent are generally paid for financing both types of plants; although Falk and Stober (37) suggest that, for water at least, the rate may be somewhat higher than this.

Something of the philosophy of time-interest rate relationships is also pertinent to this discussion. As we have seen, an interest rate is needed to bring all cost and benefit data to a common and, therefore, comparable place in time. This allows present costs to be compared with future benefits. It also determines how much extra we must pay for an expensive treatment plant to be able to have it now but pay for it in a series of payments rather than all at once. It is, then, both an equalizer in economic analyses and the opportunity cost of money (96).

Because government has certain tax advantages over the private corporation and more so over the private individual, as well as for a number of other reasons, there are many interest rates that prevail at any one time (47) (55) (71) (96). This is unfortunate when conducting a benefit-cost analysis, because it would obviously be preferable to use a common interest rate for all the time-equalizing involved. Water resources projects are normally evaluated using the government's interest rate, which is lower because of government's taxing power and hence lower-risk value than is the private rate (47) (71) (95). Krutilla and Eckstein (71) have suggested, however, that an alternative to making a public investment in water resources projects which would keep the overall economy at approximately the same level of activity would be a tax cut.

This would simply allow more spending in the private sector, rather than investing as the public body. However, these authors (71) have said, if the private parties choose to invest the money gained from the tax cut, they would do so at the private interest rates, producing more revenue than had the public money been invested at the government rate. Consequently, they conclude, there must be a middle-ground interest rate that more nearly approximates the true social investment cost in water resources development (71).

These authors have merely highlighted the fact that our economy is not operating perfectly or "optimally," or else there would be only one rate for all investors and borrowers. They went on, however, to estimate what this middle-ground interest rate should be, and although they have been severely criticized (96) for the incompleteness of their assumptions, they have demonstrated that an evaluation of two real-life alternative plans being considered in the United States would favor one alternative at the conventional government rate of interest and would favor the other alternative if the higher, imputed interest rate were used. So interest rate does make a difference. Falk and Stober (37) have demonstrated the differences it would cause in the cost of supplying water, all other things being equal.

In the end, the selection of the rate of interest to be used is another policy decision, a value judgment, that must be made (5) (96). Prest and Turvey have said (96), however, that longer periods of time will tend to minimize the effect of errors that might be made in this judgment. But they have concluded cleverly that whereas the problems

of choosing interest rates are compelling academically, "The truth of the matter is that, whatever one does, one is trying to unscramble an omelette, and no one has yet invented a uniquely superior way of doing this" (96).

SOCIAL VALUE JUDGMENT

Subjective decision-making or judgment is, almost by definition, purely philosophical. Engineers engage in judgment, of course, of varied technological sorts: from population predictions, through the choice of safety factors, and on to countless other sizing, loading, and operating decisions comprising a sound design. Economists must more qualitatively judge the effects of intangible factors, speculate about "the market," and argue philosophy about interest rates, risks, and uncertainties. But all of us from our earliest years learn to recognize what is pretty or ugly or okay, in addition to what is big or small, hot or cold, green or blue. We also begin to realize that we may prefer things, call them pretty, if they are large, or warm, or large or warm enough. And so we learn that quantity and quality are not so easy to distinguish. Quite logically the truth of this extends to the area of water and waste treatment plant design; perhaps more poignantly than to other areas of engineering, since quality here is the central theme of the surrounding calculus.

It is sometimes frustrating to the engineer and the economist who know that concrete blocks and potatoes should serve society's needs, that the public is living either in tar-paper shacks or pine-panelled

studies, either starving or ordering cherries jubilee. So even if the engineers and economists in their wisdom may be able to decide how the baking of a cake should best be done, the public with its infinite capacity for taste will still decide whether the resulting cake is, indeed, "done." Getting the job done cheaply or on time and just getting the job done, then, may be two different things.

Consequently, because the cooks of this world work for the eaters of this world, the cooks must know something of the eater's culinary desires, or they soon lose their jobs. Even if they do not particularly like cherries jubilee and consider their consumption to be merely wasteful ostentation, nonetheless they had better be able to produce palatable cherries jubilee when the demand arises. Engineers and economists charged with "cooking up" good quality water for the environment are in much the same position as these chefs. Twenty-first century man is destined to have much more time and economic ability than he presently has to consider and improve the quality of his life. Rather than concerning himself so much with what he needs and can afford, he will ask himself more often, "What do I want?" (80) (103) (132). The engineers and economists, then, must have a feeling for supplying their client's pleasures, as well as his needs.

While these technicians are much like the public's chefs, their responsibilities are much greater. They must also realize that to spend money and materials preparing cherries jubilee for one segment of society may cause starvation to fall to another, perhaps even larger,

segment. Consequently, though the decision about who is to eat how much of what may be purely political, the engineers and economists must be able to incorporate something of the relative and relevant judgments necessary to make these decisions into their evaluations of the reasonable alternatives. There is a considerable body of literature lamenting that superior procedures for including obscure secondary and most of the intangible effects of water resources development do not now exist (20) (33) (69) (91) (92) (96) (109).

Review of many books and articles indicates that at least four major areas of judgment must presently be entered by planners, and that all four areas cannot easily be explored analytically, if at all. These judgment problems include adjudication of numbers of people benefiting (greatest good for the greatest number); local, regional, or national benefits in conflict; public vs private welfare; and degrees of hazard, desirability, nuisance, criticality or other influences that each constituent has for the user to whom it is important. Although there are some problems with cost evaluation, apparently the four judgment decision listed here, as well as most evaluation problems in general, arise in benefit calculations. These four areas of concern are discussed separately below.

Greatest Good for the Greatest Number

Senate Document 97 (95) states that, "Hardship and basic needs of particular groups within the general public shall be of concern, but care shall be taken to avoid resource use and development for the benefit of a few or the disadvantage of many." This policy

has been discussed and emphasized by others (111)(127). Bylund (15) has presented an excellent discussion of the abilities of vested interest groups, whether they be minority or majority groups, to amass public support behind their cause through organized appeals. More objective methods of "taking care" that minority benefits are kept in true perspective during the evaluation procedure are needed. A TVA report (111) has also discussed the problem of assigning priorities to groups whose interests are similarly vested but whose supporters differ in numbers alone. At present if tangible benefits do not reflect these differences, they are only subjectively included in the analysis (16).

Local, Regional, and National Benefits in Conflict

Not only intangibles require judgment; there are elusive secondary benefits that also are included in economic analyses only abstractly at present. The crux of this problem lies in being able to define the scope of the project on one hand and to define the internal breadth of scope that each of the benefiteres will fill on the other. It may be, for example, that the objective of the project is to maximize regional net benefits; but local fishermen and water skiers from the entire region may be in conflict as to how the water should be used. The fishermen may prefer leaving the stream to run free while the water skiers want it to be impounded to provide a larger area for skiing (111). The tangible primary and secondary benefits from each alternative may be about equal. The numbers of fishermen and skiers may be about the same. Indeed the intangible benefits to each may

appear to be equal. But is there no way to account for the regional standard of living benefits that would accrue as a result of having a more diversified recreation area available? Except in an abstract way, apparently there is not.

A large number of authors (5) (13) (55) (59) (91) (96) (99) (109) (111) (127) have stressed the points that 1) the objective of water resources development is to maximize net benefits to the nation as a whole, 2) that the benefits to local concerns, public or private, must ultimately be paid for by the entire economy, and 3) that there is a great difference in both the costs and the benefits of development if a local, regional, or national scope or objective is adopted. Where conflicts arise there is apparently no method of analysis or part of an overall analysis that can resolve or account for these differences alone. The implication from these sources is clear, however, that regional benefits are to be preferred over local benefits, and national benefits are to be preferred over both, even if their numerical dollar values are apparently equivalent. On the other hand, present policy insists (95) (127) that these differences be left out of the economic analysis at first, but then superimposed subjectively on the economics when that portion of the evaluation is completed.

Private vs Public Welfare

Buckminster Fuller has said (41), "Solo wealth is to common wealth as x is to x^4 ." If this is exaggeration to make a philosophical point, so be it; but there is evidence in the water resources field as well that public benefits are to be granted priority over private

benefits (51). Indeed as Arrow (5) has pointed out, public benefits inherently are greater than private benefits; the difference is merely obscure. He cites the case of medical care of infectious diseases and concludes (5), "Hence, to justify itself an investment in public health, including medical care of infectious diseases, need not expect to be fully made up from fees charged to patients."

Howe (55) has reiterated the interest rate problem that was discussed earlier, which arises as a conflict between governmental and private investment. It is in the area of this sub-chapter, social value judgment, that the choice of an interest rate for water or waste disposal development must be made. Choosing the lower, government interest rate is one way of assigning a priority to social investment, which forces benefits to be shoved forward in time, to benefit future generations as well as the present ones (71). The problem remains, however, of choosing among conflicting users, who may include both public and private benefiter, which one should be given priority. Today's methods of analysis do not include an objective way of doing this.

The Hazard-Nuisance Continuum

Kneese (69) (70) has noted that for different constituents of water, different degrees of influence are visited on the same or different users. In other words, cyanide can kill, while turbidity only annoys. Still further, oxygen is corrosive to pipes, but the presence of it is essential to fish life. More sticky is the conundrum that although BOD per se is harmful to no one, it is synergistic to fish

suffocation, but synergistic only to swimmers' nuisance. Thirty mg/l of BOD, then, may cause death of fish, annoyance of a swimmer, and probably very little discernible effect at all at a water treatment plant. The intangible effects of all three influences could hardly be expected to be the same. Furthermore the loss of life from cyanide must be far more "damaging" than the annoyance by turbidity; the ratio of foregone costs of their removal at a downstream water treatment plant, then, is probably not indicative of their true relative importance.

Analytical methods for evaluating projects today do not include procedures for objectively weighing or assigning these differences (70) (91) (103) (127).

The Problem of Double Counting

The four judgment areas listed here, and particularly the first three, appear to be highly interrelated. Indeed they may be. National welfare is public welfare and is bound to include more people than local welfare. Furthermore tangible benefits to the nation are likely to be greater as a result of a project than are the tangible benefits to a local farmer or laundry or bottling company. Thus many of the effects discussed here may well be included, and rather easily so, in the straightforward economic analysis. Indeed Senate Document 97 (95) stipulates that economic analysis should be conducted independently of social or intangible analysis, presumably for the very purpose of avoiding double counting.

Still intangible effects are to be included in the final evaluation (95) (127). There are no objective methods today for doing

so, but there would be obvious value to the engineer to "reduce the indeterminate elements with which he deals to a minimum" (127).

Several authors (127)(129) have warned that evaluation should not be made on the basis of political bias or to show pork-barrel-like favoritism. Double counting can occur almost without conscious effort when the analyst has a vested or other-than-purely-objective interest in a project. On the other hand, where methods are not available to account for "indeterminate elements," they should be devised if at all possible. They should provide for avoiding double counting, but they should allow us to "develop our water resources on the widest possible base and in as objective a manner as possible" (127).

NEED FOR IMPROVED METHOD OF EVALUATION

This sub-chapter will serve to summarize what has been learned from the existing literature, as well as to highlight from still further references the main conclusion to be drawn from all this, which is that there is need for improved methodology for evaluating waste treatment alternatives.

In the very beginning of this paper, Cleary's (20) call for improved "philosophy and practice" of waste treatment design and management was cited. Following that, it was shown that attitudes and practices of today often lack coherence necessary to plan and manage water quality comprehensively. This has resulted from incomplete or even antagonistic overlapping of the areas of engineering technology, economic analysis, and social value judgment. It can be concluded from the literature cited that in each area there is considerable

awareness of specific problems and solutions, but that the three areas have not been melded to form a well-tuned conceptual apparatus for producing an "optimal" plan.

We know, for example, that technology exists to produce any degree of water quality desired, but still the concepts of quality and pollution are not clear to engineers and are certainly not coherently related at the present time. Water quality standards are believed by most authors to be both necessary and advantageous, but no one seems to know what values should be set. McKee and Wolf (89) have done a monumental job of outlining water quality requirements for many users; but these same authors, strangely, were as strongly opposed as anyone has been to the setting of standards, because they felt there was not enough scientific evidence to justify them.

In the field of economics considerable literature was reviewed which stated that economic analysis is one of the important bases for evaluating courses of action. The benefit-cost ratio method was reviewed in some detail, as were the many investment criteria that follow from its use. Still the area of intangible and elusive secondary benefits is a quandary to all who have faced the evaluation problem.

Judgment decisions in pollution control planning are numerous and varied. We seem to know without being told that the principle of the greatest good for the greatest number should be preserved, but today there is no objective way that engineers can do this in preliminary designs of waste treatment alternatives.

So apparently there is a need for a refurbishing and collation of old principles into a generalized, formalized procedure for considering

pollution and its control. It might be asked, "Why should an engineer attempt to do this?" Why not wait for the economists and political scientists to improve planning procedures, and then let the engineers provide what services of theirs are necessary to implement the newer plan? The answer is that pollution exists today primarily as a result of the failure of engineers to recognize what economists and political scientists already know. As Kneese (70) has said, "Failure of municipal and industrial waste dischargers to consider that subsequent water uses may be made more expensive or foreclosed entirely by the discharge is perhaps the basic element of the pollution problem." So the truth is that the "problem" has for some time been at the waste outfall waiting to be engineered away. The economy and the people were being ignored, at least in part, by engineers who were designing the least expensive treatment plant for their client, and not necessarily the most beneficial plant for all concerned. Consequently engineering procedures need to be brought up to date with economic procedures; little would be gained by forging ahead in economics alone, leaving engineering to tail along behind as it traditionally has.

These sentiments are not solely those of the writer. Frankel (39) has pointed out that one of the most important aspects of water quality "management" is the development of methods for evaluating the cost and benefit interrelationships "in any complex system of multiple use and reuse of a water resource." Eliassen (32) said the same thing this way: "The goal of research in engineering economy should be to optimize costs to industry, municipalities, and other higher levels of

government with the benefits to be derived by all of the users of the stream for any purpose whatsoever--in other words, a true evaluation of the benefit-to-cost ratio of all of the engineering projects."

A recent (1966) report of the National Academy of Sciences (92) has stressed the need for coordinated procedures "by which to combine methods and organizations so as to mediate the tension between technical and economic rationality and legal and political conceptions of justice and self-determination." Several reports (33) (91) (92) (109) have accented the urgency of developing new, engineering, decision-making procedures even in the vacuum of information and meaningful cause and effect relationships that exists today.

Armed with the background material surveyed here and the need expressed by so many for a new and different approach for considering the pollution problem, then, the writer sets out in the following chapter to develop a framework that can be followed in considering waste treatment alternatives for any type of client or waste situation. The final product is not perfect; it is an expedient. But it is collected in its philosophy and applicable in its practice. It is unfortunately true, though, that "the inherent complexity of the problem, plus conceptual and informational deficiencies, make fully optimal solutions an unattainable goal" (69).

III. PROPOSED METHOD

A new, modern method for evaluating waste treatment alternatives is needed. This chapter attempts to develop one. Included are proposed improvements in both the practice and philosophy of engineering technology, economic analysis, and value judgment.

QUALITY AND POLLUTION

For the purposes of engineering design and evaluation it is suggested that quality and pollution must be defined in a more rigorously quantitative way than has been used in the past. Furthermore it is proposed that the two terms signify different degrees of the same thing and that they can be related by an analytical expression. This equation is

$$Q_R - Q_D = P. \quad (5)$$

That is, the difference in the qualities of a raw waste, Q_R , and that desired of the treatment plant effluent, Q_D , is pollution, P . Furthermore, a treatment process must be designed to remove precisely this same difference, P . Each of the parameters, Q_R , Q_D , and P , should be considered as a list of constituents and their concentrations. Whereas the names of the constituents will remain the same in each list, the values of concentration in the quality lists can be mathematically subtracted to give the concentration values in the pollution list. It is as simple as, "three apples minus one apple equals two apples." Table 2 demonstrates the procedure.

TABLE 2
PROPOSED RELATIONSHIP BETWEEN QUALITY AND POLLUTION

Q_R		-	Q_D		=	P	
Constituent	Concentration*		Constituent	Concentration*		Constituent	Concentration*
Chloride	50		Chloride	150		Chloride	0†
Color	15		Color	5		Color	10
Hardness	240		Hardness	100		Hardness	140
Iron	5		Iron	1		Iron	4
Manganese	2		Manganese	0.5		Manganese	1.5
Sulfate	400		Sulfate	250		Sulfate	150
Suspended Solids	200		Suspended Solids	25		Suspended Solids	175
...							
...							

*In appropriate units.

†Negative values can be considered as zero or no problem.

Unquestionably the determination of the concentrations for Q_D is the technological problem of greatest uncertainty today. The translation of constituent concentrations from the downstream user's point back to the waste treatment plant through both time and space has been studied in some detail for oxygen and salinity almost exclusively, and there is considerable work left to be done. The fate of most constituents of natural waters has not yet been accurately described. Another area of concern that has only recently begun to be studied is the variation in constituent concentrations with time at one place. Both streams and wastes vary in both their flows and their contaminant levels. Certainly as much sophistication as is available and applicable should be utilized to determine the concentration levels of both Q_D and Q_R . It should be noticed, however, that whether one solves Equation 5 once or many times (to include a range of possible values), a single value of concentration for each constituent must be chosen each time. Hopefully at least one value can be sensibly estimated for all the constituents of concern.

It cannot be overemphasized that the quality desired in the finished water, Q_D , should be determined first. There are two possible methods for finding Q_D . The method to be preferred is listing and computing the effluent quality based on the necessary or desired stream qualities of the downstream users. The other alternative is simply to insert the constituent names and appropriate concentration levels that are dictated by the prevailing legal standards. Professional responsibility will usually result in the first method being used, and hence

in a better effluent quality than the legal standards will require, since they must be rather minimal goals to account for cases of unusual hardship.

Next the waste should be characterized for those constituents that appeared on the Q_D list. This determines Q_R . In terms of defining either quality or pollution it should be noted that there is no need for measuring constituents that did not appear on the Q_D list, although other measurements may have to be made to improve or monitor plant operation. For example, if color, dissolved oxygen, and turbidity are the only constituents of concern to the downstream users, there is no need to know the concentration of BOD in the waste to determine what pollution is; although BOD would probably be necessarily measured to monitor performance of meeting the dissolved oxygen requirement. However, BOD should not be called or confused with pollution in this case.

Thirdly, the two lists of names and numbers of the two qualities should be subtracted to determine the amount of those constituents listed that must be removed or added by treatment to produce the desired effluent quality. These differential concentrations define what constituents are of concern and the magnitude of the "lumps" of each that must be removed. This is the degree of waste nonutility, and for quantitative design purposes should be adequate to define "pollution."

Previous definitions of quality as being all the good things about water and of pollution as being any one "significantly" bad thing about water are inadequate. The growing and necessary awareness that wastewater is simply a part of a usable-reusable water spectrum or a

resource demands that the two concepts be related. The proposed expression, Equation 5, is believed to be adequate to describe this relationship. The remainder of the proposed method for evaluating waste treatment alternatives consists of an economic operation on the pollution list, P.

ECONOMIC CONSIDERATIONS

Despite the many inherent weaknesses of the benefit-cost ratio method of analysis, it would seem that its use is well-established, and it is destined to remain with us for some time to come. Consequently, it is believed that the proper way to proceed with an improved method of analysis is simply to modify that existing procedure. The primary change proposed here is that intangible factors be included in the analysis in a more objective way than has traditionally been used. The strongest objection to including these factors in the economic analysis up till now has been that they could not be included quantitatively. Therefore, since they are to be so included here, their introduction to the body of the economic analysis seems justified.

To begin, it is assumed that the total annual benefit of removing or altering the concentration of each constituent of a waste consists of three parts: readily-measurable or estimable dollar benefits either directly or indirectly resulting from the quality change, which will be redefined here in a lump as "primary" benefits, B_p ; the elusive part of the secondary benefits that would have monetary value if they could be estimated, B_s ; and nonmonetary benefits or intangibles, B_I , which can be monetarily evaluated only by imputing a

dollar value to them. Algebraically, then,

$$B_T = B_P + B_S + B_I. \quad (6)$$

It is obvious from the definitions of B_S and B_I that this equation is, and has been, difficult to solve. However, an expedient for using this equation is developed here as follows.

If, for the specified removal(s) of each constituent on the pollution list, the terms B_S and B_I , are taken together, their sum can be expressed as some multiple of B_P . On the assumption, then, that if we knew the three values of the different benefits, one of them could be expressed simply as a linear proportion of the other two, we may write

$$B_S + B_I = NB_P. \quad (7)$$

Consequently,

$$B_T = B_P + NB_P, \quad (8)$$

or

$$B_T = (1+N) B_P. \quad (9)$$

Now if we let

$$1+N = M, \quad (10)$$

then,

$$B_T = MB_P. \quad (11)$$

It would be nice to stop here. Plainly M should be some number equal to or greater than 1.0. If the true value that M would take for each constituent and each concentration thereof were known, the analysis would be complete. However, in the previous chapter it was shown that M is a function of at least four things: scope of the project (m_S), public or private affiliation of those benefited (m_A), the number of benefiteres (m_N), and the importance to the user of the constituent in question (m_I). It can be stated, then, that

$$M = f(m_S, m_A, m_N, m_I), \quad (12)$$

where the m 's are numbers that, when combined, will yield M .

It is probably academic as to which method of combining the m 's is to be preferred. The problem resolves itself, really, to choosing whether to add the m 's or to multiply them, and having decided that, to assigning them some value.

For the first part, the writer prefers and recommends multiplication. This is, in part, because there is some precedent for using 'multipliers' to estimate total benefits (59). More importantly, though, it is felt that multiplication will avoid, rather than compound, problems of double counting; even though it might seem at first glance that adding these effects separately would be a better way of avoiding overestimation, particularly since multiplication tends to compound numbers to higher products than addition does to sums.

In the first place, this last assumption about multiplication is not entirely correct. Four ones are four, while one to the fourth

power is still one. Near 1.5 to 1.6 it makes little difference whether the four numbers are added or multiplied, the answer is very nearly the same. Indeed as long as the four numbers are kept to relatively low values, the value of M will be of the same order of magnitude whether the m values are added together or multiplied together.

So simply to combine the four m 's there is little apparent advantage of multiplication over addition, as long as the values of the m 's range from about 1 to 3. Clearly, though, the m factors suggested here define effects that in all cases will not be mutually exclusive. As a result, double counting may occur, regardless of whether we add the m 's or multiply them. Therefore, the analyst must be kept acutely aware when choosing values for the m 's that these interrelationships may exist in his particular case. It is strictly the writer's opinion that the multiplication process symbolizes interrelationships of this kind more poignantly than does the process of addition. Hence he chooses to write

$$M = m_S \times m_A \times m_N \times m_I. \quad (13)$$

It should be stated here, however, that other methods for representing M may one day be presented that will work more satisfactorily than the proposed one, and that both they and the method presented here remain to be verified. However, this relationship is proposed as a start. Choosing values for the m 's is clearly a judgment matter, and so is left for now to be discussed in the judgment section below.

If what has been developed for estimating benefits to be derived for each constituent is now adequate, though, the problem still remains of comparing these benefits to the costs of achieving them. The benefit-cost ratio method clearly implies that the benefits should be divided by the costs to obtain the value of the ratio. Here another slight but hopefully significant modification is suggested. It is proposed that engineers keep benefit data and cost data separately, and that benefits never be divided by costs to choose one of the alternatives as being superior. The reason for this is to avoid the pitfall of believing that the alternative with the highest ratio is superior to all the others. We saw earlier that this is not necessarily so, that other investment criteria may be valued more highly. It was also pointed out that the decision about which of the alternatives is the one to be adopted is the investor's and not the engineer's to make. Therefore, it is proposed that for engineering purposes the benefit data should be compiled and listed for each alternative and that cost data for each alternative be listed with the benefits, but that the values of the ratios need not be computed. If they are computed for each alternative, then other calculations should also be included to show which of the alternatives is most efficient, maximizes net benefits, or meets other possible criteria.

JUDGMENT PROBLEMS

The remaining necessity for developing the proposed method of evaluation is to assign values to the m 's derived above. There is

little or no precedent to guide us. It is obvious that the lower limit on M is 1.0, so the lower limit on all four m values should also be 1.0. The problem, then, is to decide upon the upper limit of M .

Fuller's (41) comment that private wealth is to public wealth as x is to x^4 is not much help. Of less help are the English words "priceless," "dear," and "precious." We need a value that will strike a medium between those words, though, and phrases like "silent spring" and "death of the sweet waters."*

We do know that the tangible benefits alone to be obtained from waste treatment are often less than the costs necessary to realize the quality goals established (115), and that people are willing to pay up to ten times more for home softening than they would have to pay if their water were municipally softened (57). We can only assume that for the removal of constituents more harmful to man than hardness, he would be willing to pay an even higher premium. It would seem on the basis of these findings alone that M should range from 1.0 to above 10.0. Using this conclusion as a guide, the writer proposes the hypothetical values for the individual m 's as shown in Table 3.

It is to be noted that a range of values is given for each category. This is considered proper and necessary, because there are undoubtedly users or constituents that should be valued slightly

*Silent Spring by Rachel Carson and Death of the Sweet Waters by Donald Carr are contemporary books bemoaning the ills of pollution in the environment.

TABLE 3

HYPOTHETICAL MULTIPLIERS FOR THE PROPOSED
METHOD TO ACCOUNT FOR SECONDARY
BENEFITS AND INTANGIBLES

$$M = m_S \times m_A \times m_N \times m_I.$$

Item			Value
m_S - SCOPE			
	Local		1.0 - 1.1
	Regional		1.1 - 1.2
	National		1.2 - 1.3
m_A - AFFILIATION			
	Private		1.0 - 1.1
	Public		1.1 - 1.2
m_N - NUMBER OF PEOPLE			
	Number of People = N, $N \geq 10$		$\log_{10} N$
m_I - CONSTITUENT INFLUENCE			
	Synergistic to Nuisance	Pleasant Low	1.0 - 1.2
	Nuisance	Desired Slight	1.2 - 1.4
	Synergistic to Hazard	Important Moderate	1.4 - 1.6
	Hazard	Critical High	1.6 - 1.8

differently, even though they may both be best described by just one of the categories listed. Furthermore, because different constituents vary in their mode of influence on the same or different users, several possible descriptive sets of categories are listed for evaluating m_I . It might also be noted that for 10 to 10,000 people benefiting, M can vary from 1.0 to 11.2, depending on the other three m values.

There is one other judgment decision that must be made repeatedly that is almost hidden, though implied, in this analysis. That is the "estimation" of B_p for each constituent. In Chapter II several accepted methods for evaluating primary benefits were mentioned. However, these traditional methods are applicable for assigning benefits to a water resources "project," and not exclusively to the water quality consequences thereof. Moreover benefits such as foregone operating costs at downstream water treatment plants or fish and wildlife benefits must of necessity be estimated in terms of lump-sum, aggregate benefits. It is clearly a judgment decision as to how these total benefits to each user must be apportioned among the several constituents that influence the user's utility of the water.

Experience is probably the only available aid, but future research in this particular area could prove to be invaluable. A first point that can be made, however, is that there is no reason to believe that the separate primary benefits among the constituents important to one user should add up to the total benefit estimated. Just one and perhaps any one of the constituents of concern could obviate all the benefits to be derived. For example, if dissolved oxygen and pesticides are critical to fish life, each one could be

assigned a B_p equal to the entire primary benefit estimated, since each could cause the death of all the fish available. This severity, of course, is only a function of the concentration on the pollution list and the toxic effect of that amount of chemical on the organisms. It is not to be confused with, nor is it double counting to also include, the relative beneficial effect on society of preserving and enjoying fish and wildlife that is to be estimated with m_I . The point to be made here is that the total estimated monetary benefit accruing to each user is the upper limit on B_p for each constituent and concentration on the one user's pollution list and not for all of them on the list. This is the same problem, really, only in benefit calculation, as the problem of trying to estimate the separable costs of removing just BOD or just suspended solids in a secondary treatment plant. It is still an omelette that defies unscrambling.

SUMMARY OF THE PROPOSED METHOD

A condensed outline of the proposed method is presented in Table 4. If one follows this step-wise procedure, a rather comprehensive evaluation of treatment alternatives should be possible. This condensed version does assume, however, that certain economic data are available, and that collection and reduction of other necessary, technical field data can continue to be done in the traditional ways. Therefore, the entire next chapter has been devoted to the development of a detailed evaluation study in a hypothetical situation. A much more cursory example is presented in Tables 5 and 6, and the economic criteria satisfied in this example are summarized in Table 7.

TABLE 4
SUMMARY OF PROPOSED METHOD

$$Q_R - Q_D = P.$$

$$B_T = m_S \times m_A \times m_N \times m_I \times B_P.$$

1. Define and list the important water uses to be protected and the effluent quality constituents and concentrations necessary to do so. This determines Q_D .
2. Characterize the waste with regard to those constituents entered in the Q_D list. This determines Q_R .
3. Solve the equation, $Q_R - Q_D = P$, to determine the amounts of those constituents that must be removed from the waste.
4. Measure or estimate B_P for each constituent and concentration on the several users' pollution lists.
5. Assign m values for each constituent and the user naming it on the pollution list and calculate B_T for each constituent's removal.
6. Prepare costs for several alternative treatment methods, at least one of which will provide all the prescribed removals on the pollution list.
7. Present cost data for each removal alternative along with data describing the total benefits, ΣB_T , for all the constituents removed by each alternative.

TABLE 5
EXAMPLE BENEFIT ANALYSIS

Constituent	Required Removal*	Use	m_S	m_A	m_N	m_I	$B_P^\dagger$ ¢/1000 gal	B_T benefit units
Color	10	REC	1.1	1.2	3.0	1.3	1.5	7.7
Hardness	140	DOM	1.0	1.2	4.0	1.4	3.0	20.2
Iron	4	DOM	1.0	1.2	4.0	1.3	1.0	6.2
Manganese	1.5	DOM	1.0	1.2	4.0	1.4	1.0	6.7
Sulfate	150	IND	1.1	1.0	1.0	1.5	2.0	3.3
Suspended Solids	175	REC	1.1	1.2	3.0	1.4	2.0	11.1
...								
...								

*In appropriate units.

[†]Argument about the particular values in this column would be moot, but there are considerable references to indicate that the order of magnitude is correct (9) (24) (26) (39) (40) (50) (53) (56) (57) (72) (75) (76) (84) (92) (93) (98) (136).

TABLE 6

EXAMPLE BENEFIT-COST COMPARISON

Treatment Alternative	Constituents Removed Adequately	B _P ¢/1000 gal	ΣB _P ¢/1000 gal	B _T benefit units	ΣB _T benefit units	Cost, C ¢/1000 gal
1) Secondary	Iron	1.0		6.2		
	Manganese	1.0		6.7		
	Susp. Solids	2.0	4.0	11.1	24.0	7.0
2) Chem. Precip. + Filtration + Secondary	Hardness	3.0		20.2		
	Iron	1.0		6.2		
	Manganese	1.0		6.7		
	Susp. Solids	2.0	7.0	11.1	44.2	17.0
3) Carbon Ads. + Chem. Precip. + Filtration + Secondary	Color	1.5		7.7		
	Hardness	3.0		20.2		
	Iron	1.0		6.2		
	Manganese	1.0		6.7		
	Susp. Solids	2.0	8.5	11.1	51.9	23.0
4) Ion Exchange + Carbon Ads. + Chem. Precip. + Filtration + Secondary	Color	1.5		7.7		
	Hardness	3.0		20.2		
	Iron	1.0		6.2		
	Manganese	1.0		6.7		
	Susp. Solids	2.0		11.1		
	Sulfate	2.0	10.5	3.3	55.2	47.0

TABLE 7
SUMMARY OF ECONOMIC CHOICES
RESULTING IN EXAMPLE PROBLEM

Treatment Alternative	$\Sigma B_T/C$	$\Sigma B_T - C$	$\Delta \Sigma B_T / \Delta C$	$\Sigma B_P/C$
(1)	3.43	17.0		0.57
			2.02	
(2)	2.60	27.2		0.41
			1.28	
(3)	2.26	28.9		0.37
			0.14	
(4)	1.17	8.2		0.22

In Table 5 the pollution list, P , used as an example in Table 2 is repeated. Then, for each constituent and downstream user, B_T is computed from 1) values of B_p that supposedly are available or estimable, and 2) the engineer's judgment of appropriate values for the several m 's. The result is a list of benefits, no longer in direct monetary terms, but in "benefit units" that are consistent within the analysis and, therefore, comparable.

In Table 6 possible treatment alternatives and their appropriate costs are compared to the beneficial removals of those constituents listed that could be expected from each process. It is interesting, but should not be surprising, that for all four of the alternatives evaluated, the ratios of the primary benefits alone to the costs of the treatment process, $\Sigma B_p/C$, are less than 1.0.

Whereas the writer feels that the engineering analysis is completed with the presentation of the material in Tables 5 and 6, nonetheless some of the economic criteria discussed earlier are summarized in terms of this example in Table 7. It is of interest that alternative 1 has the greatest benefit-cost ratio ($\Sigma B_T/C$), alternative 2 adds the greatest net benefit for the increment of cost added over the preceding alternative ($\Delta \Sigma B_T/\Delta C$), and alternative 3 produces the maximum net benefits ($\Sigma B_T - C$). It should also be noted that alternative 4 has a benefit-cost ratio of greater than 1.0, but is less efficient economically than any of the other alternatives.

IV. HYPOTHETICAL PROBLEM

INTRODUCTION

To clarify the applicability and potential of the proposed method the following hypothetical problem has been developed. It has purposefully been presented as a story with a main character, an engineer who attempts to use the method just outlined. The reason for the example is to illustrate that engineers are people having to deal with other people, and that both the engineer and the public may not have all the answers and the data that pollution control requires. Nonetheless, the engineer is expected to perform in a professional way and to find an answer.

Hopefully it can be seen that although our engineer is more pragmatist than scientist, more naive than novel, and even though he seems to blunder at some points, nonetheless he is led by the proposed procedure to a rather comprehensive and most reasonable answer. He is portrayed almost as a simpleton not to imply that most engineers are like him, but indeed so that he can hopefully be called an extreme case. The idea is that if he succeeds, anybody can. The situation he faces, however, is believed to be reasonably typical of the real world, although it is purely fictional also.

SCOPE OF THE PROBLEM

Figure 4 depicts a make-believe stream along which are located several different water users. The uses include irrigation, industrial water supply, fish and wildlife preservation, recreational

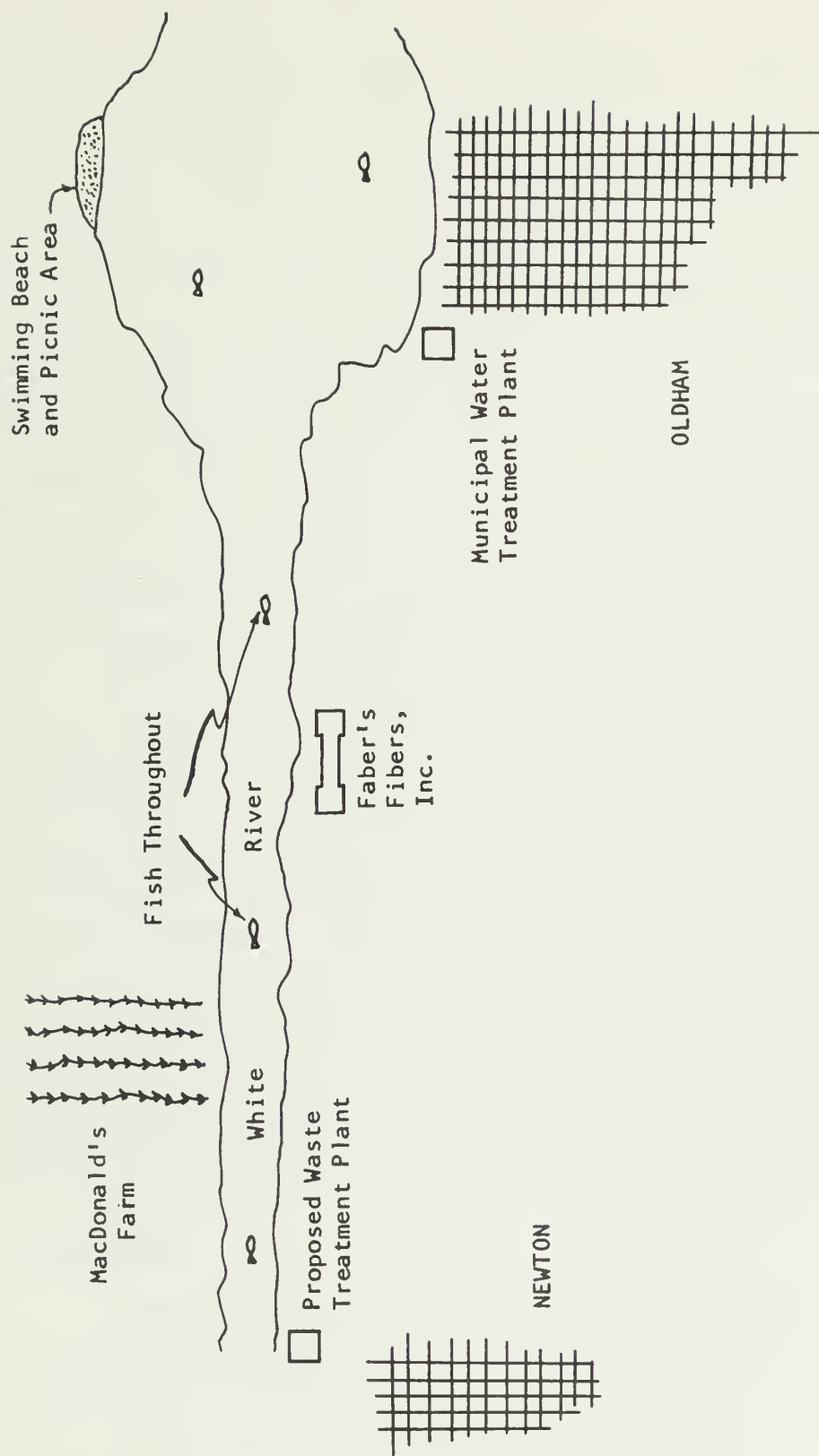


FIGURE 4. HYPOTHETICAL STREAM SITUATION

and esthetic enjoyment, and domestic water supply. In this example each use is represented only one time.

It is assumed that the town of Newton has heretofore used only individual septic tanks for waste disposal but has grown and prospered to the point that a waste treatment plant capable of processing two million gallons of waste per day is now needed. The citizens and the Town Council are now prepared to invest wisely and reasonably in such a venture. This example will attempt to discover how wisely and how well that investment can be made. The analysis includes considerations of treatment plant alternatives only and not those surrounding the necessary but attendant collection system.

To begin, let it be further assumed that the Town Council has requested the city's engineer to prepare a preliminary report concerning what the treatment plant must be able to do, what types of treatment are available to do the necessary job, and approximately what the annual costs of the possible alternatives will be. On the basis of this report the Town Council will invite bids from private engineering firms for final design and construction. The following rationale will represent the information gathered and the analyses performed by the engineer while preparing his report.

THE WHITE RIVER

The stream to which the proposed plant will discharge its effluent is the White River, which is really more creek than "river," but that is its name. Hydrologically it is an effluent stream, meaning that there is almost always some base flow being contributed

from ground water storage. It will be assumed that flow data have been collected by the U. S. Geological Survey since 1939 at gaging stations located at both Newton and Oldham.

During the assumed period of record (1939-1966) the average daily flow at Newton has been 75 cfs (48.5 mgd). Ninety percent of the time the flow is greater than 3.1 cfs (2.0 mgd). The peak daily flow, which was recorded on March 21, 1951, was 308 cfs (199 mgd). The average daily flow at Oldham, located sixteen miles downstream from Newton, has been 338 cfs (218 mgd). Ninety percent of the time the flow here is greater than 13.0 cfs (8.4 mgd). The peak daily flow, which also occurred on March 21, 1951, was 1395 cfs (901 mgd).

Low flows usually occur during the month of August. For five to ten days each year during August the flow at Newton drops to zero. Downstream at Oldham there exists a natural impoundment on the stream which will hold a four-day supply of water for that community; and although the flow at Oldham has dropped as low as 3.0 cfs on several August days, there has never been a serious shortage for water supply purposes.

DOWNSTREAM WATER USERS

Farmer MacDonald

Two miles downstream of Newton, J. J. MacDonald owns and operates a farm on which he grows soy beans, corn, and, occasionally, wheat. Because rainfall has not been sufficient for the needs of his crops, for several years he has withdrawn 1.0 mgd of White River water for supplemental irrigation. This water is withdrawn for about 100

days each year, during the growing period of his crops. Farmer MacDonald is satisfied with the results of his irrigation program and profits \$10,000 annually from the sale of his harvest. Prior to his use of irrigation water his crops netted a profit of only \$6000 annually. The benefit of this irrigation water, then, is about 4 cents per 1000 gallons.

Mr. MacDonald is not aware of specific quality levels of White River water, but they appear to him to be good enough for his purposes.

Faber's Fibers, Inc.

Six miles below Newton on the White River there is a small synthetic fiber manufacturing plant called Faber's Fibers, Inc. This is not a particularly large business, but most of the plant's products are sold to a textile manufacturing firm in Oldham, and the plant employs 250 people from Newton, Oldham, and the surrounding area.

Faber's Fibers, Inc. constructed a water treatment facility at the inception of the business in which both cooling water and process water are treated, as well as the water supplied to the employees for drinking purposes. This water treatment plant provides 0.25 million gallons of water per day for all the plant's uses.

The waste from Faber's Fibers, Inc. consists primarily of cooling water with about ten percent of the flow being process wastes. The total waste flow is 0.20 million gallons per day. This waste is discharged untreated to the White River.

Benefits to this industry that would accrue from protecting or enhancing the quality of the White River upstream of the industry's water intake will be of the foregone-treatment-cost type. The value of these benefits will depend on the constituents involved and the amounts of each that are removed or otherwise kept to acceptable (present) levels in the stream.

Fish Life

The White River has been popular among sport fishermen for many years. Large and small mouth bass, crappie, blue gill, perch, and several species of trout have been plentiful in this river for as long as veteran fishermen in the area can remember. Weekends and summer vacation periods bring many fishing enthusiasts to the White River from the surrounding area and from as far as 100 miles away. Occasionally tourists will stop and spend an afternoon fishing in this river before continuing their journey; angling success is that good.

There has been a noticeable slackening of success in landing trout downstream of Faber's Fibers, Inc. following the construction of this factory in 1952. Local fishermen have speculated that the increased temperature of the water caused by the heated cooling-water effluent from this industry has been the reason for the decrease in trout population. No fish of any species have been killed, however, and there are still abundant trout to be found upstream of this industrial outfall.

The engineer estimated monetary benefits from the presence of these fish based on the following factors: 1) the ten bait shops

in the area average about ten dollars per day during the 150-day fishing season, 2) the five hardware or sporting goods stores in Newton and Oldham make about twenty dollars per day on the sale of fishing gear alone during the year, 3) local fishing license sales total about \$500 per year, and 4) if 100 trips are made per year from an average distance of forty miles away at nine cents per mile, there are about \$360 spent per year on travel to fish in this river. In other words, about \$31,000 are spent directly on fishing in the White River each year. From the flow data the engineer estimated that the average flow during the fishing season was about 50 mgd; consequently the tangible benefits derived from the fish being there and being catchable are approximately 0.4 cent per thousand gallons of river water. He further estimated that 1500 fishermen use the stream each season.

Recreation and Esthetics

There is today a large bathing beach located across the river and downstream from Oldham. Like Topsy, the popularity of this spot just grew, until now the County Public Works Department has taken the upkeep of this park area under its administrative and maintenance wings. Sequentially this department has added picnic tables, rest stations, and a bimonthly program of trash pickup and grass mowing; just this past summer the Oldham Recreation Department provided two lifeguards for the first time.

Saturdays and Sundays during the summer months normally attract 300 to 500 swimmers to this park and beach, and an estimated

750 persons swam there on July 4, 1966. No fees are charged for the use of these facilities.

During a 100 day swimming season an estimated 20,000 swimmers use this particular beach. The City of Oldham and the County Public Works Department spend about \$12,000 per summer providing lifeguards and maintaining this swimming and picnicing area; but it is apparently worth more than that to the citizenry, because folks flock there on weekends and holidays and complain if the grass is too high or the garbage cans have not been emptied. To date, though, they have not complained about the quality of the water. The engineer estimated, then, that the ten million gallons of water that flow through the impoundment per day during the summer months provide a tangible benefit of six cents per thousand gallons to the swimmers.

There are numerous other but smaller "swimming holes" that are popular all along the White River within the stretch between Newton and Oldham. Although the enjoyment derived here is doubtless at least as great per swimmer, the engineer had no way of estimating a tangible benefit to these swimmers, and so he added no further amount to the six cents per thousand gallons. He did note, however, that recreation and esthetic benefits are derived all along the stream and that they should not be considered to accrue at the beach alone, some eighteen miles below the proposed Newton outfall.

Domestic Water Supply

The City of Oldham takes its supply of municipal water from the natural impoundment, approximately sixteen miles downstream of the

proposed waste treatment plant at Newton. This water is treated in a 4.5 mgd softening and sand filtration plant and distributed to the 28,000 people living in Oldham. Benefits to be derived here from protection and enhancement of the quality of the White River are, as in the case of the industry upstream, equivalent to foregone costs of increased treatment.

WATER QUALITY REQUIRED BY USERS

Farmer MacDonald

Newton's engineer visited with J. J. MacDonald to learn what specific quality levels the farmer has found necessary for his irrigation water, and what present constituents of the White River, if any, are in some way harmful to his crops or to the soil. Mr. MacDonald said that he was quite satisfied with the water he had been taking from the White River, although he was unaware of any specific constituents that might be harming the soil or his plants. His main concern was that the White River should stay exactly as it has been so he would have no worries about quality. He was not aware of the present quality of the river with regard to any specific constituents or properties other than, "sometimes the water is a little muddy, but that doesn't seem to hurt anything."

Mr. MacDonald, in answer to the engineer's question, reported that several other farmers along the White River were now considering the use of supplemental irrigation, although they do not now employ it. Their crops, according to Farmer MacDonald, are the same as his own.

The engineer felt that without undertaking a full-scale research project he should, noenttheless, have some idea of the quality requirements for this irrigation water. To arrive at these numbers he consulted with McKee and Wolf's, Water Quality Criteria (89). From what he found in this reference and from what he knew of the White River and Farmer MacDonald's operation, he synthesized the quality array shown in Table 8.

TABLE 8
FARMER MacDONALD'S IRRIGATION QUALITY REQUIREMENTS

Constituent	Concentration, mg/l or as noted
Boron	0.5
Chloride	200
Percent Sodium	50
Residual Sodium Carbonate,* meq/l	1.25
Sulfate	300
Total Dissolved Solids	700

$$^*RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++}), \text{ all in meq/l.}$$

Faber's Fibers, Inc.

Several meetings with Clinton R. Faber, president of Faber's Fibers, Inc., and Mortimer Burbage, the industry's chief chemical engineer whose responsibilities include the operation of the water treatment facilities, produced considerable information for the engineer's report.

The water treatment processes for this industry are rather advanced, since part of the operation of this plant requires very pure water. Because there are water quality requirements that differ among pulp processing and viscose rayon manufacture, cooling water, and drinking water, the incoming water is split and sent through various degrees of treatment.

All of this incoming water is first aerated, then softened by the excess lime process, and passed through rapid sand filters. Sixteen percent of the filtered water is then chlorinated and serves as the drinking water and laboratory bench supply. About thirty percent of the filtered water is passed through a cation exchange resin to remove any remaining iron and manganese and is then used as process water for pulp preparation and the production of rayon fibers. The remaining fifty-four percent of the water is used just as it comes from the filters and serves as cooling water and for power production. Table 9 summarizes the water quality requirements for these four internal industrial purposes as submitted by Faber's Fibers, Inc. to the engineer.

Table 10 is a compilation of minimum raw water quality requirements synthesized by the engineer and based on the information supplied by Faber's Fibers, Inc.

As stated previously there is no provision made at Faber's Fibers, Inc. for waste treatment. However, the waste flow does pass through a large holding pond that has a theoretical detention time of 48 hours. Occasional but not routine measurements are made of pH and five-day BOD of the effluent of this pond. The chemical engineer mentioned

TABLE 9
INTERNAL INDUSTRIAL WATER QUALITY REQUIREMENTS

Constituent or Property	Concentration, mg/l or as noted			
	Cooling	Rayon	Pulp	Drinking
Alkalinity			50	To
Color, units			5	Meet
Copper			5	USPHS
Hardness, CaCO_3	50	55	10	Drinking
Iron	0.5	0.0	0.05	Water
Iron and Manganese	0.5	0.0	0.05	Standards
Manganese	0.5	0.0	0.03	
pH		7.8-8.3		
Silica			25	
Total Solids			100	
Turbidity	50	0.3	5	

TABLE 10
MINIMUM RAW WATER QUALITY - FABER'S FIBERS, INC.

Constituent or Property	Concentration, mg/l or as noted
Alkalinity, CaCO_3	250
Color, units	10
Coliform Organisms, per 100 ml	10,000
Chlorides	500
Hardness, CaCO_3	350
Iron	1.0
Iron and Manganese	1.0
Manganese	0.5
Odor, T.O.N. units	15
pH, units	6.5-8.5
Silica	50
Sulfate	300
Total Dissolved Solids	500
Turbidity, units	15

in passing to Newton's engineer that the pH of this effluent is usually between 7.0 and 8.5 and that the BOD is almost always around 35 to 40 mg/l. Routine discharge procedure from this pond consists of allowing the pond to discharge at all times except when the river stage is below the crown of the effluent outfall. During these times the outfall is closed with a gate valve and kept closed until either 1) the river stage rises, or 2) the pond becomes full, whichever occurs first. Both the chemical engineer and Mr. Faber mentioned to the engineer that there have been no complaints about this procedure to date.

Fish Life

Reference to Jones (64), Klein (68), and McKee and Wolf (89) aided the engineer in arriving at the values of quality parameters desired for the protection of fish and aquatic life which are shown in Table 11.

Recreation and Esthetics

Quantitative values for water quality parameters desired for recreational waters, which support the pleasurable pursuits of swimming, boating, and just plain esthetic enjoyment, are perhaps the most difficult to assign. The engineer chose the values shown in Table 12 for the White River after referring to McKee and Wolf (89) and calling upon his own knowledge of present conditions, as well as with a certain admitted amount of arbitrariness.

TABLE 11
DESIRED WATER QUALITY FOR
PRESERVATION OF FISH LIFE

Constituent or Property	Concentration, mg/l or as noted
BOD	20
Chloride	<50
Chlorine	< 0.1
Dissolved Oxygen	5.0 for 16 hr. of any 24- hr. period; never <3.0
Hydrogen Sulfide	< 0.3
Iron	< 0.5
Lead	< 0.5
Suspended Solids	20
Temperature	<24°C Apr.-Dec. <15°C Dec.-Apr.
Total Dissolved Solids	400

TABLE 12
WATER QUALITY DESIRED FOR RECREATIONAL
AND ESTHETIC PURSUITS

Constituent or Property	Concentration, mg/l or as noted
ABS (Surfactants)	1.0
Coliform Organisms, No. per 100 ml	2000
Color, units	25
Nitrate	20
Odor, T.O.N. units	15
pH, units	6.5-7.8
Phosphate	1.5
Suspended Solids	30
Turbidity, units	25

Domestic Water Supply

Newton's engineer met with the city engineer and the water treatment plant superintendent of Oldham to gather information about the raw water quality requirements for that city and its treatment facilities. He asked specifically for a list of properties and constituents of the White River water that this treatment plant dealt with routinely, and what concentrations of these constituents could be tolerated without unreasonable changes or increased costs to the normal operating procedure. He was supplied with the list given in Table 13.

After receiving this list he asked the city engineer of Oldham about other constituents not included on this list but that are included in the U. S. Public Health Service Drinking Water Standards. He was assured by the Oldham engineer that other constituents, such as cadmium, selenium, or arsenic, are in such low concentrations in the White River that they have never presented a hazard or need for special attention or treatment and that the likelihood of their appearance in the foreseeable future is extremely remote. He was assured further that if the White River contained the constituents shown on the submitted list in the noted concentrations or less, the Oldham treatment plant could provide suitable and acceptable water to its customers.

Newton's engineer accepted the constituents and their concentrations as submitted by the City of Oldham.

TABLE 13
RAW WATER QUALITY REQUIREMENTS FOR CITY OF OLDHAM

Constituent or Property	Concentration, mg/l or as noted
Carbon Chloroform Extract	50
Chlorides	500
Coliform Organisms, No. per 100 ml	10,000
Color, units	40
Hardness, CaCO_3	350
Iron	1.0
Manganese	0.5
Nitrate	50
Odor, T.O.N. units	15
Phenols	0.005
Sulfate	300
Total Dissolved Solids	1,000
Turbidity, units	50

SUMMARY OF STREAM QUALITY REQUIREMENTS

Table 14 is a compilation of all the constituents or properties important to the subsequent users of the White River below the proposed Newton sewage treatment plant. In his report the engineer said of this listing, "The names and numbers in this table represent the reasons for our concern about waste treatment."

PRESENT STREAM QUALITY

The one large remaining problem was to determine the degree of removal of the listed substances from the waste flow to provide stream concentrations no higher than those specified for the downstream points of use; but a paradoxical problem arose at this point. It may have been that some of the listed constituents would not be in troublesome concentrations in the waste, and hence there should have been no reason for measuring these constituents in the stream. For those constituents that would be in high enough concentration to warrant attention, however, the necessary degree of their removal could not be calculated without first knowing the present level of these substances in the stream. The quandary, then, was whether to characterize the waste first or to determine the levels of the constituents in the stream.

In this particular case the engineer knew that considerable data had been collected on the quality of the White River by state and federal organizations. He also knew that virtually no data would be available about the waste, since most of it had been discharged to septic tanks previously and part would come from new industries. He decided, therefore, to learn as much as he could about the stream first.

TABLE 14
SUMMARY OF STREAM QUALITY REQUIREMENTS

Constituent or Property	Water Use	Required or Desirable Stream Concentration at Point of Use
ABS (Surfactants)	REC	1.0 mg/l
Alkalinity, CaCO_3	IND	250 mg/l
BOD	FISH	20 mg/l
Boron	IRR	0.5 mg/l
Carbon Chloroform Extract	DOM	0.2 mg/l
Chloride	IRR	200 mg/l
	IND	500 mg/l
	FISH	50 mg/l
	DOM	500 mg/l
Chlorine	FISH	0.1 mg/l
Coliform Organisms	IND	10,000 /100 ml
	REC	2,000 /100 ml
	DOM	10,000 /100 ml
Color	IND	10 units
	REC	25 units
	DOM	40 units
Dissolved Oxygen	FISH	5 mg/l for 16 hr., never <3 mg/l
Hardness, CaCO_3	IND	350 mg/l
Hydrogen Sulfide	FISH	0.3 mg/l

TABLE 14 (Continued)

Constituent or Property	Water Use	Required or Desirable Stream Concentration at Point of Use
Iron	IND	1.0 mg/l
	FISH	0.5 mg/l
	DOM	1.0 mg/l
Iron and Manganese	IND	1.0 mg/l
Lead	FISH	0.5 mg/l
Manganese	IND	0.5 mg/l
	DOM	0.5 mg/l
Nitrate	REC	20 mg/l
	DOM	50 mg/l
Odor (T.O.N.)	IND	15 units
	REC	15 units
	DOM	15 units
Percent Sodium	IRR	50 percent
pH, units	IND	6.5 - 8.5
	REC	6.5 - 7.8
Phenols	DOM	0.005 mg/l
Phosphate	REC	1.5 mg/l
Residual Sodium Carbonate	IRR	1.25 meq/l
Silica	IND	50 mg/l
Sulfate	IRR	300 mg/l
	IND	300 mg/l
	DOM	300 mg/l

TABLE 14 (Concluded)

Constituent or Property	Water Use	Required or Desirable Stream Concentration at Point of Use	
Suspended Solids	FISH	20	mg/l
	REC	30	mg/l
Temperature	FISH	24°C Apr.-Dec.	
		15°C Dec.-Apr.	
Total Dissolved Solids	IRR	700	mg/l
	IND	500	mg/l
	FISH	400	mg/l
	DOM	1,000	mg/l
Turbidity	IND	15	units
	REC	25	units
	DOM	50	units

Two sources of background quality data for the White River were available. One was a single year's record reported by the U. S. Public Health Service in their annual compilation of data as collected by the National Water Quality Network program. The White River had been added to the list of streams to be surveyed just the previous water year. The second source was a bulletin on the surface water quality of the state's major streams published by the State Water Survey. This publication included data gathered on approximately twenty days per year for the last five years. Because this record was longer, the engineer decided to rely on it for those constituents that were reported in both places.

He considered performing statistical analyses on all of these data to find the average concentration, or the value that was exceeded only ten percent of the time, or the "expected value;" but he decided that for his purposes and to conserve time he would simply scan the record and choose a value that appeared to be exceeded only once in a while--perhaps eighty to ninety percent of the maximum value recorded. This is what he did, and the values he chose from the two references are shown in Table 15. The constituents or properties listed here are only those for which there was an entry in Table 14.

The engineer noted that of the twenty-nine constituents or properties listed as important by the water users in the White River basin, only ten had not been monitored by the state or federal agencies. The unmonitored ones, though, were most striking to him by their omission. Besides aluminum they were ABS, BOD, chlorine, coliform organisms, dissolved oxygen, hydrogen sulfide, odor, phenol, and suspended solids--

TABLE 15
PARTIAL QUALITY OF THE WHITE RIVER

Constituent or Property	Reported Stream Concen- tration, mg/l or as noted
Alkalinity, CaCO_3	250
Boron	0.2
Carbon Chloroform Extract	0.1
Chloride	40
Color, units	10
Hardness, CaCO_3	350
Iron	0.02
Iron and Manganese	0.03
Lead	<0.006
Manganese	0.01
Nitrate	18
pH, units	7.6-8.1
Phosphate	1.0
RSC, meq/l; Ca = 90 mg/l, Mg = 30 mg/l	-4.48
Silica	8.4
Sodium = 30 mg/l, K = 1.3 mg/l	%Na = 15.7
Sulfate	210
Temperature	25°C Apr.-Dec. 10°C Dec.-Apr.
Total Dissolved Solids	620
Turbidity, units	40

inclusive of perhaps the most often-mentioned constituents that people regard as pollution indicators, and certainly those regarded as quality indicators by virtue of their inclusion in the list by the water users. Newton's engineer found this very interesting and commented on it in his report.

For the missing constituents he synthesized values in the following ways. First he dropped chlorine from the list altogether, since it would not be expected in the waste flow. However, if part of the resulting treatment included chlorination of the effluent, the 0.1 mg/l criterion for fish-life protection should not be overlooked. He noted this in his report.

The engineer was equipped to perform the BOD, dissolved oxygen, odor, suspended solids, and turbidity determinations, although he had only a limited time available to spend monitoring the stream. He decided to collect several samples on three different days (this was in July) and to determine, among other things, both the BOD and turbidity of these samples. Since he had found a turbidity value of 300 units in the reported literature, he reasoned that if a correlation existed between turbidity and BOD in his samples, he could interpolate or extrapolate as required to estimate the BOD value. That is, he would plot the values of BOD and turbidity found for his few samples, draw the curve that fit the data best, and pick off the BOD value where turbidity equaled 300 units. This he did, and he arrived at a

value of 30 mg/l as the five-day BOD of the stream.*

The dissolved oxygen levels in the stream on the three days were 5.5, 5.4, and 7.1 mg/l. He chose to use 5.5 mg/l. Similarly he chose a value of 25 mg/l for suspended solids and a Threshold Odor Number of 15 units. This odor was definitely not hydrogen sulfide, so he chose to enter 0.0 mg/l for this compound.

He was able to persuade a friend of his who worked as a lab technician at the county hospital in Oldham to perform confirmed tests for coliform organisms on three samples of river water collected on days when the flow was relatively low. His friend reported that the three samples indicated Most Probable Numbers of 2900, 4300, and 12,000 per 100 ml. The engineer chose to use a value of 10,000 per 100 ml.

The value for ABS was estimated as 0.5 mg/l based on values for streams that the engineer had read in recent literature. For phenol he simply guessed 0.005 mg/l, presuming that the Oldham engineer had entered the value that he often encountered at the Oldham water treatment plant.

NECESSARY EFFLUENT CONCENTRATIONS

Stream concentrations either measured or synthesized were assumed to occur at the points of use; fish and recreation uses were assumed to be significant throughout the reach of the stream; and flow rates at the various points of use were assumed to increase linearly

*The engineer was lucky. In natural streams a good correlation rarely exists between BOD and turbidity. When it does, it may be either positive or negative, depending on the stream and watershed characteristics, and probably countless other things (117).

from Newton to Oldham, as shown in Figure 5. With this information the engineer was able to estimate the effluent concentration necessary to protect the downstream users according to the relationship

$$q_e C_e + q_s C_s = (q_s + q_e) C_d, \quad (14)$$

or

$$C_e = C_d + \frac{q_s}{q_e} (C_d - C_s). \quad (15)$$

In this equation q_e is the effluent flow rate, 2 mgd in this case, q_s is the flow rate of the stream at the point of use, C_s is the present concentration in the stream, C_d is the concentration in the stream that should not be exceeded or that would be desirable at the point of use, and C_e is the necessary effluent concentration. The engineer solved this equation for each combination of constituents and users that appeared in Table 14, and his results are given in Table 16.

CHARACTERIZATION OF THE WASTE

There remained, then, the problem of determining the levels of all these constituents in the expected waste. Subtraction of the values in Table 16 from those of the waste should indicate the removal efficiencies required of the treatment facility.

By far the greatest amount of the engineer's time and effort in preparing his report was spent in deriving estimates of the raw waste strength. There was no sewer presently carrying the waste from which he could collect samples for analyses. This was to be the first

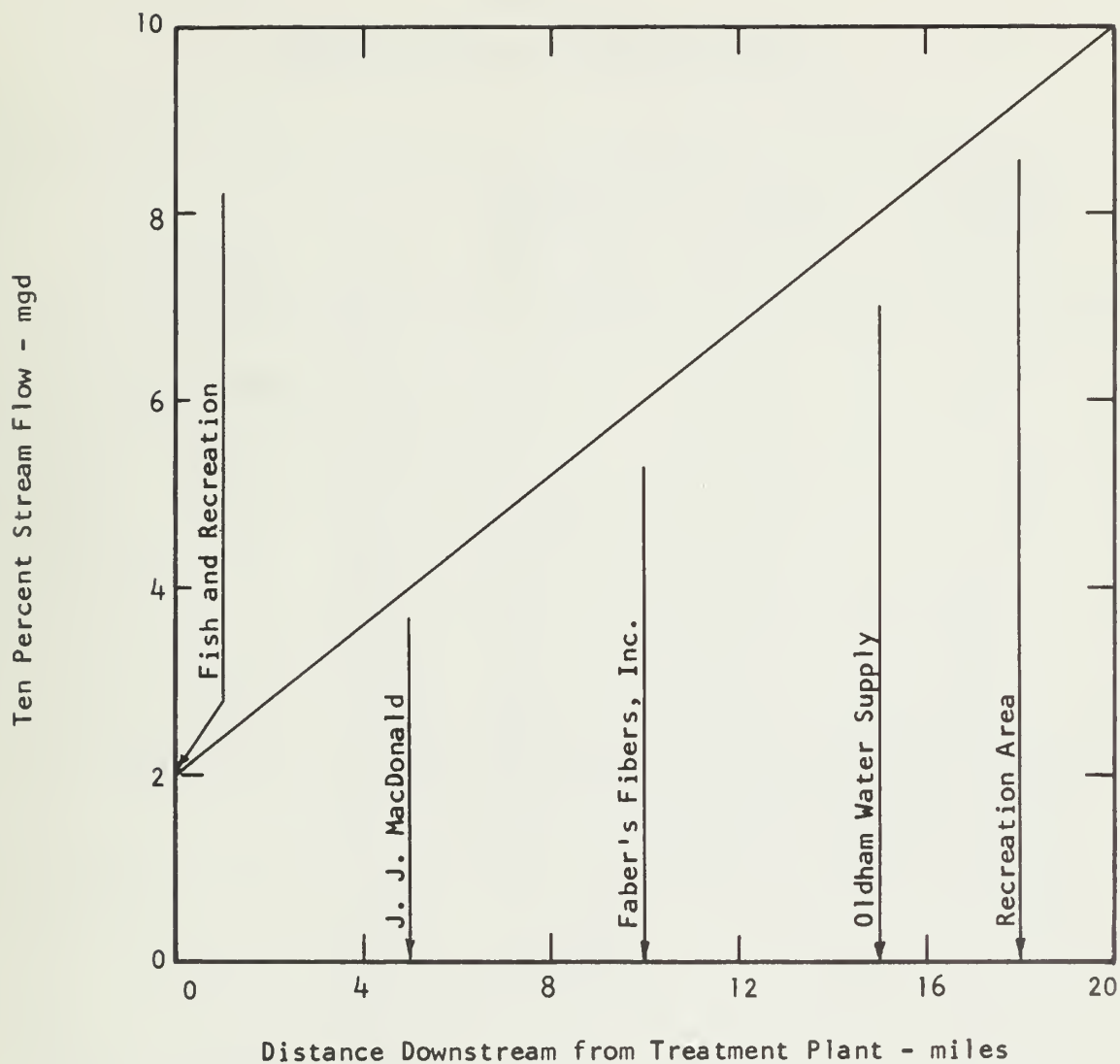


FIGURE 5. STREAM FLOW AT POINTS OF WATER USE MORE THAN 90 PERCENT OF THE TIME

TABLE 16
NECESSARY EFFLUENT CONCENTRATIONS*

Constituent	Use	Desired Stream Conc., C_d	Present Stream Conc., C_s	Necessary Effluent Conc., C_e	
ABS	REC	1.0	0.5	1.5	
Alkalinity, CaCO_3	IND	250	250	250	
BOD	FISH	20	30	10	**
Boron	IRR	0.5	0.2	1.1	
CCE	DOM	0.2	0.1	0.6	
Chloride	IRR	200	40	520	
	IND	500	40	1,880	
	FISH	50	40	60	
	DOM	500	40	2,340	
Coliforms	IND	10,000/100 ml	5,000/100 ml	25,000/100 ml	
	DOM	10,000/100 ml	5,000/100 ml	30,000/100 ml	
	REC	2,000/100 ml	5,000/100 ml	5,000/100 ml †	
Color	IND	10 units	10 units	10 units	
	REC	25 units	10 units	40 units	
	DOM	40 units	10 units	160 units	
D.O.	FISH	5.0	5.5	4.5	
Hardness, CaCO_3	IND	400	350	400	
	DOM	400	350	400	
Hydrogen Sulfide	FISH	0.3	0.0	0.6	
Iron	IND	1.0	0.02	3.9	
	DOM	1.0	0.02	4.8	
	FISH	0.5	0.02	1.0	
Iron and Manganese	IND	1.0	0.03	3.9	
Lead	FISH	0.5	<0.006	1.0	
Manganese	IND	0.5	0.01	2.0	
	DOM	0.5	0.01	2.5	

TABLE 16 (Concluded)

Constituent	Use	Desired Stream Conc., C_d	Present Stream Conc., C_s	Necessary Effluent Conc., C_e	
Nitrate	REC	20	18	22	
	DOM	50	18	178	
Odor, T.O.N.	IND	15	15	15	
	REC	15	15	15	
	DOM	15	15	15	
Percent Sodium	IRR	50	15.7	107	
pH	IND	6.5-8.5 units	6.5-7.6 units	††	
	REC	6.5-7.8 units	6.5-7.6 units	††	
Phenols	DOM	0.005	0.005	0.005	
Phosphate	REC	1.5	1.0	2.0	
RSC	IRR	1.25 meq/l	-6.10 meq/l	15.9 meq/l	
Silica	IND	50	8.4	175	
Sulfate	IRR	300	210	480	
	IND	300	210	570	
	DOM	300	210	660	
Suspended Solids	FISH	20	25	15	***
	REC	30	25	35	
Temperature	FISH	24°C	25°C	23°C	***
		15°C	10°C	20°C	
Total Dis. Solids	IRR	700	620	860	
	IND	500	620	620	†
	FISH	400	620	620	†
	DOM	1,000	620	2,520	
Turbidity	IND	15 units	40 units	40 units	†
	REC	25 units	40 units	10 units	***
	DOM	50 units	40 units	90 units	

* units are mg/l except as noted.

*** $C_s > C_d$; treatment may allow stream quality enhancement.

† $C_s > C_d$; accept C_s for the time being.

†† Await estimates of waste pH for this value and means of correction if necessary.

collection-system and treatment-plant facility to be constructed in the Town of Newton, so the engineer was forced to estimate all quantities either on the basis of reports in the literature or on information gathered from visits with some of the contributing industries. None of these estimates was made easily; even flow rates and infiltration rates had to be estimated rather crudely or in a very general way. Quality parameters were in some cases even more difficult to predict. Even though the analysis lacked precision, the engineer wished to make some estimate for the levels of all the constituents that the downstream users had indicated were important to them. There follows, then, a summary of what appeared in the engineer's report regarding the quality of the expected waste.

There were five major sources from which wastes would flow to the proposed plant. Besides domestic flow there would be contributions from a shopping center and three industries. The industries included a hardware manufacturing plant, a soy bean processing plant, and a high-protein food supplement manufacturer.

Locke, Stock, and Barrow, Inc. produces nuts, bolts, screws, door knobs, and the like. The waste from this plant is, therefore, high in acidity and iron, as well as other metals. Soy-Shall-You-Reap, Inc. produces soy bean oil for sale to other more specialized manufacturers and also makes cattle feed from the remainder of the bean. This waste is rather high in BOD and low in suspended solids. It is virtually all organic material. Vita-Bita Corporation makes a bite-sized condiment that is sold primarily to athletes and especially to

weight lifters. It is purported to give quick energy and to contribute to good muscle fiber. It is ninety-five percent protein, so the organic waste from this plant is mostly carbohydrate, fats, and fibrous material. Still the five-day BOD of the waste is rather low, although suspended solids are quite high. Also there are considerable amounts of hardness and alkalinity in this waste. Table 17 summarizes the contributions of all five of these sources.

Using these limited data and observations from reported literature, the engineer compiled Table 18 showing his estimates of the concentrations of all the important substances that would result when the flows from all five waste sources were combined.

PRELIMINARY PLANT DESIGN

The engineer now had the quality data necessary to begin considering the design of the waste treatment plant. He reasoned that the plant should be able, if economically and technically possible, to remove those substances and the corresponding amounts of them indicated by subtracting the necessary or desired effluent quality (Table 16 or Q_D) from the quality of the waste (Table 18 or Q_R). Because several users required different levels of the same constituent, and because there were simply so very many constituents with widely varying degrees of desired removal to be considered, the engineer could see that just subtracting the concentrations in the two tables would not suffice. He also needed to estimate the relative gains to be derived from attaining the several indicated removals of the various substances. To make this estimate he applied the procedure for estimating

TABLE 17
WASTE SOURCES AND THEIR ESTIMATED STRENGTHS

Source	Flow, mgd	Constituent	Concentration*
Domestic	1.0	BOD	200
		Color	40 units
		Hydrogen Sulfide	5
		Odor	40 units
		Suspended Solids	300
		Temperature	25°C
		Total Dissolved Solids	500
Commercial Shopping Center	0.1	Alkalinity, CaCO ₃	400
		BOD	400
		Suspended Solids	350
Locke, Stock and Barrow, Inc.	0.3	Acidity, CaCO ₃	2,000
		BOD	15
		Boric Acid	300
		Chromium (hexavalent)	10
		Copper	80
		Iron	160
		pH	2.1 units
		Suspended Solids	45
		Zinc	2.0
Soy-Shall-You- Reap, Inc.	0.25	Alkalinity, CaCO ₃	200
		BOD	420
		COD	650
		Color	200 units
		D.O.	0
		Grease and Oil	60
		pH	8.0 units
		Suspended Solids	10
		Temperature	120°F
Vita-Bita Corp.	0.35	Alkalinity, CaCO ₃	1,220
		BOD	55
		Calcium	420
		COD	110
		D.O.	5.8
		Iron	14
		Magnesium	60
		pH	7.5 units
		P ₂ O ₅	245
		Suspended Solids	2,000

*mg/l or as noted.

TABLE 18
ESTIMATED DESIGN WASTE CHARACTERISTICS

Constituent	Concentration*
ABS	2.0
Alkalinity, CaCO_3	100
BOD	185
Boron	7.5
CCE	50
Chlorides	300
Coliforms	5×10^7 /100 ml
Color	70 units
D.O.	0
Hardness, CaCO_3	500
Hydrogen Sulfide	10
Iron	25
Iron and Manganese	26
Lead	0.5
Manganese	1.0
Nitrate	50
Odor, T.O.N.	80
pH	7.3 units
Phenols	0.01
Phosphate (PO_4)	40
RSC	-185 meq/l
Silica	20
Sodium	25%
Sulfate	150
Suspended Solids	525
Temperature	28°C
Total Dissolved Solids	850
Turbidity	500 units

*mg/l or as noted.

the benefits of protected water quality that was outlined in Chapter III. These subtraction and ranking operations are completed and summarized in Table 19.*

The engineer next derived cost data for several alternatives of waste treatment similar to those described in Figures 1 and 2 in Chapter II. Having these data available, he then compared the cost of each alternative with the total "benefit units" to be derived from the several removals that each treatment alternative could provide. Because a recent state law required that all municipal wastes should receive at least secondary treatment, his alternatives began with that process. These comparisons are shown in Table 20.

The engineer presented Tables 19 and 20 as his final exhibits before the Town Council of Newton.

EPILOUGE

From the engineer's data shown in Tables 19 and 20, the members of the Town Council were able to prepare Table 21. This

*It can be noted from this table that the procedure can become much more complicated than was indicated by the simple example given in Chapter III. Coliforms, color, suspended solids, and turbidity were required at different concentration levels here by different users. Consequently the benefits to all users for each level attained in the effluent had to be computed. The column, MB_p , in Table 19 indicates the value attained by multiplying the four m 's together and then times B_p for each user. The B_T column shows the sum of the MB_p values for the constituent removal required by the first user in the set, but which total benefits accrue at least partially to all the users concerned with that constituent. It might also be noted that the engineer chose to lump the removals of iron and manganese together and compute a B_T only one time, since he apparently felt that the required removals for all three users, though different, were essentially the same. Engineering judgment, then, has not been supplanted. If anything, it has been honed to a finer edge.

TABLE 19

REQUIRED REMOVALS AND BENEFIT ANALYSIS FOR
HYPOTHETICAL WASTE TREATMENT PLANT

Constituent	Use	Necessary Effluent Concentration*	Required Removal*	m ^s	m ^A	m ^N	m ^I	B _P , ¢/1000 gal	MB _P , benefit units	B _T , benefit units
ABS	REC	1.5	0.5	1.1	1.2	4.3	1.3	0.5	3.7	3.7
BOD	FISH	10	175	1.15	1.2	3.2	1.5	0.4	2.65	2.65
Boron	IRR	1.1	6.4	1.0	1.0	1.0	1.7	3.0	5.1	5.1
CCE	DOM	0.6	49.4	1.1	1.2	4.45	1.6	3.0	24.7	24.7
Coliforms	(1) DOM	30,000/100 ml	5 x 10 ⁷ /	1.1	1.2	4.45	1.6	1.9	17.9	
	IND		100 ml	1.2	1.0	2.4	1.6	2.0	9.2	
	REC			1.1	1.2	4.3	1.6	3.5	31.8	58.9
	(2) IND	25,000/100 ml	5 x 10 ⁷ /	1.2	1.0	2.4	1.6	1.9	8.8	
	DOM		100 ml	1.1	1.2	4.45	1.6	2.0	18.8	
	REC			1.1	1.2	4.3	1.6	3.5	31.8	59.4
	(3) REC	5,000/100 ml	5 x 10 ⁷ /	1.1	1.2	4.3	1.6	4.0	35.3	
	DOM		100 ml	1.1	1.2	4.45	1.6	2.1	19.5	
	IND			1.2	1.0	2.4	1.6	2.2	11.5	66.3
Color	(1) REC	40 units	30 units	1.1	1.2	4.3	1.4	3.0	24.8	
	IND			1.2	1.0	2.4	1.3	1.0	3.75	28.55
	(2) IND	10 units	60 units	1.2	1.0	2.4	1.3	2.0	7.5	
	REC			1.1	1.2	4.3	1.4	3.5	27.8	35.3
D.O.	FISH	4.5	+4.5	1.15	1.2	3.2	1.8	0.4	3.2	3.2

TABLE 19 (Continued)

Constituent	Use	Necessary Effluent Concentration*	Required Removal*	m ^s	m ^A	m ^N	m ^I	B _p , ¢/1000 gal	MB _p , benefit units	B _T , benefit units
Hardness, CaCO ₃	IND	350	150	1.2	1.0	2.4	1.4	2.0	8.1	
	DOM	350	150	1.1	1.2	4.45	1.4	2.0	16.5	24.6
H ₂ S	FISH	0.6	9.4	1.15	1.2	3.2	1.8	0.35	2.8	2.8
Iron	DOM	4.8	21.2	1.1	1.2	4.45	1.4	4.0	32.9	
(Iron and Manganese)	IND	3.9	22.1	1.2	1.0	2.4	1.4	4.0	16.1	
	FISH	1.0	24.0	1.15	1.2	3.2	1.7	0.3	2.25	51.25
Nitrate	REC	22	28	1.1	1.2	4.3	1.2	4.0	27.2	27.2
Odor	DOM	15 T.O.N.	65 T.O.N.	1.1	1.2	4.45	1.3	1.9	14.5	
	IND	15 units	65 units	1.2	1.0	2.3	1.3	2.0	7.5	
	REC	15	65	1.1	1.2	4.3	1.4	4.5	35.8	57.8
Phenols	DOM	0.005	0.005	1.1	1.2	4.45	1.4	1.0	8.2	8.2
Phosphate, PO ₄	REC	2.0	38	1.1	1.2	4.3	1.2	4.0	27.2	27.2
Suspended Solids	(1) REC	35	490	1.1	1.2	4.3	1.4	4.0	31.8	
	FISH			1.15	1.2	3.2	1.5	0.2	1.3	33.1
	(2) FISH	15	510	1.15	1.2	3.2	1.5	0.25	1.7	
	REC			1.1	1.2	4.3	1.4	4.0	31.8	33.5
Temperature	FISH	23°C Apr.-Dec.	5°C	1.15	1.2	3.2	1.6	0.1	0.7	
		20°C Dec.-Apr.	8°C	1.15	1.2	3.2	1.6	0.1	0.7	1.4

TABLE 19 (Concluded)

Constituent	Use	Necessary Effluent Concentration*	Required Removal*	m _S	m _A	m _N	m _I	B _P , ¢/1000 gal	MB _P , benefit units	B _T , benefit units
TDS	FISH	620	230	1.15	1.2	3.2	1.5	0.1	0.7	
	IND	620	230	1.2	1.0	2.4	1.4	1.0	4.0	4.7
Turbidity	(1) DOM	90 units	410 units	1.1	1.2	4.45	1.2	2.0	14.1	
	IND			1.2	1.0	2.4	1.3	2.0	7.5	
	REC			1.1	1.2	4.3	1.4	3.0	23.8	45.4
	(2) IND	40 units	460 units	1.2	1.0	2.4	1.3	2.5	9.1	
	DOM			1.1	1.2	4.45	1.	2.5	17.6	
	REC			1.1	1.2	4.3	1.4	3.5	27.8	54.5
(3)	REC	10 units	490 units	1.1	1.2	4.3	1.4	4.0	31.8	
	IND			1.2	1.0	2.4	1.3	3.0	11.2	
	DOM			1.1	1.2	4.45	1.2	3.0	21.1	64.1

*mg/l or as noted.

TABLE 20
COMPARISON OF BENEFITS AND COSTS OF
HYPOTHETICAL WASTE TREATMENT

Treatment Alternative	Constituents Successfully Removed*	ΣB_T , "benefit units"	ΣB_P , ¢/1000 gal	Total Annual Cost, ¢/1000 gal
1) Secondary	ABS, Color (1), Iron and Manganese S.S. (1), Turbidity (1)	128.9	24.0	10.0
2) Secondary + Chlorination	Coliform (2)	188.3	31.4	14.0
3) Secondary + Chlorination + Chem. Precip.	BOD, Boron, Color (2), Hardness, PO_4 , S.S. (2), Turbidity (2)	332.5	53.65	26.5
4) Secondary + Chlorination + Chem. Precip. + Filtration	Coliform (3), Turbidity (3)	349.0	56.05	32.9
5) Secondary + Chlorination + Chem. Precip. + Filtration + Act. Carbon Ads.	CCE, H_2S , Odor, Phenols	442.5	68.8	45.2
6) Secondary + Chlorination + Chem. Precip. + Filtration + Act. Carbon Ads. + Electrodialysis	Nitrate, TDS	474.4	73.9	90.5

*Those removed in a less complete process are not included again.

TABLE 21
ECONOMIC CRITERIA RESULTING FROM
HYPOTHETICAL BENEFIT-COST EVALUATION

Treatment Alternative	$\Sigma B_T/C$	$\Sigma B_T - C$	$\Sigma B_P/C$	$\Delta \Sigma B_T / \Delta C$
1	12.9	118.9	2.40	14.85
2	13.45	174.3	2.24	11.54
3	12.54	306.0	2.02	2.58
4	10.61	316.1	1.70	7.60
5	9.79	397.3	1.52	0.70
6	5.24	383.9	0.82	

table outlines their economic choices and provides them with the necessary data to spot the alternative which best fits their objective for investment, whatever they have chosen that to be. It is interesting to note that alternative 1 has the highest ratio of tangible benefits to costs; alternative 2 has the highest ratio of "total" benefits to costs; alternative 5 produces the maximum net benefits; and that each of the alternatives from 1 to 5 is more efficient economically than the one just preceding it.

The writer is not aware of which alternative the Council decided to release for final design and construction bids; but apparently this choice has recently been made, and specifications have been given to prospective bidders. It is known, however, that the engineer, who has always been a forward-looking young man, was somewhat disgusted with the Council's choice.

V. DISCUSSION

Time for you and time for me,
And time yet for a hundred indecisions,
And for a hundred visions and revisions,
Before the taking of a toast and tea.

T. S. Eliot, from "The Love Song
of J. Alfred Prufrock."

So there it is--a method, borrowing on traditional and, therefore, safe ideas; but insisting on a fresh, ambitious step into the future of human needs. Three areas of major concern--engineering, economics, and social values--have been brought together and streamlined a bit to cast a formal, generalized procedure for objectively considering a qualitative goodness that otherwise defies description. Ciardi knew the problem faced here when he wrote (19), "This talk of the long waters is toward magic, of course, for we do live, in part, by magic, though we have lost most of the vocabulary for it. We have been taught unreasonable vocabularies of reason--unreasonable because they are not languages our feelings can live by even when our proprieties try to. Watching water go, we touch magic again, and are left dumb by it."

But the need has been established here for engineer-scientists to probe the world of quality and somehow to emerge with a reasonable, quantitative scale for it. It is hoped that even a rough-hewn dip stick with reasonably well-spaced quality marks has been whittled here. We are still a long way from adding a vernier, but the spots to be sanded and smoothed should be apparent now with this model to work from.

In the beginning it was shown that a strange diversity has grown between the terms, "quality" and "pollution." Quality has expanded to include everything good about water, while pollution has remained a confined term signifying only one or any one bad thing about water. The point was made here and became a part of the proposed evaluation method that pollution is merely the difference between two sets of quality, one good and one bad. For the two terms to be quantified there is very little other possibility for their meaning, and they surely must be related.

It was also implied early that quality standards are becoming more a part of sanitary engineering life. Furthermore, there are at least two types, legal and professional standards. Depending on the circumstances and the personalities involved, Q_D can be made to be either of these two types. If the method proposed here is used, Q_D will be determined as a first step and will be dependent on the subsequent users of the watercourse involved. If the legal standards prevailing have adequately accounted for these users, then the feeding of these standards into the analysis is justified. However, the engineer should determine for himself that all the standards are indeed indicative of conditions the users have come to expect.

Then, having decided what the quality desires of the users are, the engineer must be able to decide what these desires are worth and how much it will cost to satisfy them. In the past, procedures for making these decisions and evaluations have been incomplete. Because waste treatment is concerned more with protecting human values than

with producing a market product, municipal or industrial water treatment is far more a dollar-and-cents investment than is waste treatment. Imhoff and Fair (60) have rather beautifully, almost naively, summarized the broader perspective of the waste treatment objective: "The service rendered by a municipal sewage-treatment plant must be commensurate with its cost. Most of this service is performed not for the benefit of the municipality itself but for that of lower or riparian owners. That, however, is part of the give-and-take between civilized communities." Kneese has taken the more mundane, pecuniary view (70): "A society that allows waste dischargers to neglect the offsite costs of waste disposal will not only devote too few resources to the treatment of waste but will also produce too much waste in view of the damage it causes."

So we had to dive into the murky waters of costs and benefits, time and interest rates, double counting, uncertainty, and intangibles. Difficult as it was to stay afloat, we more or less dog-paddled to the conclusion that the benefit-cost ratio method of evaluation is conceptually neat and reasonable, in theory at least, and that it would be simpler to improve on that than to try creating an entirely new approach. Thus it was that intangibles, the real stumbling block of this analysis, were included in the arithmetic with the rest of the economic factors.

The m values suggested here are not to be considered inviolate. They are a beginning, a suggestion for later review. The aim, of course, should be to determine what m 's really exist and what their true

values are. The important point introduced here is that the m 's do exist--perhaps there are more than those suggested here--and that they do have values. The ones suggested appear to be reasonable as estimates, but it could hardly be said that the writer is opposed to change. If they require revision as a result of improved data or special circumstances, they should be changed without hesitation. Assuredly no theory would be violated. "Further research to define the relationship between the concentration of all the various types of pollution [sic] and the resulting damages is one of the most pressing needs of water resources planning" (61).

In the hypothetical problem we met an interesting character who was not blessed so much with brains or special knowledge as he was with fortitude and, perhaps doubly so, with lack of final responsibility. Nevertheless he attacked his problem with imagination and the objectivity that it and his position provided him. If there be any doubt, by the way, this engineer and the waste treatment situation were both indeed hypothetical figments of the writer's fancy. It was intended, however, that there be a similarity between this situation and any of thousands in the living world.

Some points from this hypothetical problem could stand some expansion. First of all the engineer found his knowledge of the situation limited at every turn. Still, reasonableness and engineering judgment led him to a long list of names and numbers for Q_D , Q_R , P , and the quality of the stream. In many real-life situations data are easier to obtain than they were for this poor man. The stimulus to find or estimate all the things he needed, though, was provided by his

having started with Q_D . This is unquestionably the most significant move he made, which led to his analysis being so complete by the time he finished. It would have been much simpler to guess the BOD and suspended solids concentrations of the waste and to decide that some air-blowing device and a holding tank should be built at least cost.

This suggests a second significant point of the problem, which has been reiterated throughout the paper. The engineer left the investment decision to the Town Council. The alternatives he evaluated were only those that could be provided to do the required jobs at least cost. The real problem in this multi-level evaluation process was that there were several "least" costs. The engineer's responsibilities in this area have been well summarized this way: "In the main, pollution abatement technology is an example of science at the aid of policy" (109).

A third area to be explored is the answers that the engineer got. It made little difference to the writer and certainly less to his fictional engineer what answers would result. Both of us wanted to know what the numbers were, but neither of us cared about their value per se. So there was no fabrication or working backwards or fudging introduced here. The problem was developed as it is presented. It is interesting to see, then, how not-so-outlandish the numbers are that resulted. Is it at all beyond belief that the benefit to five users of water would be \$5.00 per 1000 gallons? This is about what the benefit would have been from the most advanced treatment alternative considered, if the "benefit units" were truly dollar units. The MB_p calculation actually insists that the B_T values do have units of dollars

or cents per 1000 gallons, but because the m values are new and untested the "benefit unit" notation has been retained here. Still in all it would seem from this first solution that the m values are not very far afield.

This leads to one final comment. It might appear that the ϵ /1000 gal cost figures for the treatment plant are not fully comparable to the accumulated ϵ /1000 gal benefit values for all the downstream users, because each user does not get, apparently, the full 1000 gallons treated. Of each 1000 gallons treated it seems obvious that each downstream user will get only a portion of the total, and hence his benefits should be apportioned according to the volume of water he uses relative to those of the other users, or in other words, in relation to the flows required by each user.

This feeling should bring home once and for all that waste treatment is indeed only a facet of a larger idea called water resources development. The treatment plant is not providing all the water for these downstream users; nature and the stream bed are helping. The vital point to see, though, is that treatment costs money, and nature is, in a sense, reneging on her share of the cost. Only man pays; but the entire stream flow, many thousands of gallons of water, is being protected quality-wise by both the plant and the stream. So, provided that the engineer's hydrologic estimates were right, there will always be a full 1000 gallons of water for each of the five users protected by just one 1000 gallon slug going through the treatment plant. But also remember that the engineer did concentrate the

constituents with his dilution equation to account for differences in streamflow at the Newton plant and at the other points of use.

So, again, here is a method. Berry has said (10), "No country or area desirous of social progress will be satisfied with an unsanitary environment. This must be part of our advance toward a better standard of living for all. Our economic progress in recent years has been rapid, and we are prepared to pay for and to demand conditions and facilities which previously seemed beyond reach." Ciardi (19), more sentimentally perhaps but poignantly, has written, "I know that if the day comes when I walk my stream down Bread Loaf Mountain and find my chosen roil frothing detergents or clotted by the junk of someone's picnic, on that day I shall swear a damnation on the human race as unfit to occupy any planet." So here is a method, proposed as an aid for engineering thinking and analysis that hopefully will allow the technician to assuage one of man's worldly Hells within newly attainable economic goals.

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No! I am not Prince Hamlet, nor was meant to be;
Am an attendant lord, one that will do
To swell a progress, start a scene or two,
Advise the prince; no doubt, an easy tool,
Deferential, glad to be of use,
Politic, cautious, and meticulous;
Full of high sentence, but a bit obtuse;
At times, indeed, almost ridiculous--
Almost, at times, the Fool.

T. S. Eliot, from "The Love Song
of J. Alfred Prufrock."

VI. SUMMARY AND CONCLUSIONS

From what has been reviewed and developed here, the following conclusions can be drawn.

1. Quality and pollution as generic concepts have not traditionally been related for either the layman or the engineer. Nonetheless, if the engineer is to adequately evaluate alternatives for protecting water in the environment from reaching intolerable conditions of nonutility, a quantitative relationship between quality and pollution is required. Such a relationship has been suggested here and is

$$Q_R - Q_D = P.$$

2. Economic considerations of pollution control planning must be given complete scrutiny if the resulting plan is to be the "best" of several choices. The traditional benefit-cost ratio method of analysis has been able to evaluate alternatives only in a limited way. There has been a need for a more rational, objective economic analysis that would include nonmonetary benefits in a less subjective way. An expedient procedure for estimating the worth of these nonmonetary values and including them in the total benefit calculation has been proposed.
3. To evaluate and include these intangible values considerable search of literature has indicated that the four

most important subjective areas that need quantification are a) the scope of the user's influence on society, b) the public or private nature of the user's benefit, c) the number of people constituting each "user," and d) the degree of hazard, criticality, desirability, nuisance, or other influence that each constituent might have on the user who names that constituent as being of concern to him.

4. Final selection of the proper investment criterion to choose from among the several possible alternatives rests with the client and not necessarily the engineer who made the technical analysis of evaluation of the several alternatives.

The method or procedure developed and outlined in this paper is unfortunately not a final solution. It is a beginning. Had this problem been a simple one to solve, it would have been solved years ago. It cannot be considered solved now. Nonetheless a first step has been taken. Improvements and criticisms are heartily invited.

The writer admits to harboring some philosophical attitudes about "the pollution problem" in general and how it should be solved. He has made every effort, however, to keep philosophical remarks of his own to a minimum. On the other hand, there is a philosophy-of-engineering problem that must be squarely faced in attempting to abate pollution technically, and that is the problem of including in design

alternatives some nonconcrete, nondollar values to describe the clients' esthetic desires. This problem, though it may be or may become controversial, could not be shirked here. Indeed it may have been the most important problem faced. Hopefully it was faced rationally and objectively. That was the purpose of this work.

VII. SUGGESTIONS FOR FUTURE WORK

In view of the results obtained from this study, it is suggested that certain portions of this investigation be extended to include the following:

1. The applicability and reasonableness of the proposed method should be verified with data from a real-life waste treatment problem. From an economic point of view, it would be purer to begin with benefits and costs to determine what Q_D should be. Unfortunately data have not been traditionally reported or even gathered in a form allowing this approach. Improved data measurement will be required both to verify the expedient method proposed here and to afford the economists the opportunity to help us decide what "standards" should be set.
2. The proposed method should be extended to include water treatment plant design, as well as in-stream processes such as low-flow augmentation for altering or maintaining quality. It should be true that the relationship, $Q_R - Q_D = P$, can be applied in any situation where a quality improvement is required. Furthermore, benefit analyses for water treatment plant design have been almost as sparse as they have been for waste treatment, so there is need for continued study and verification in this sector of the field as well.

3. Concomitant with the adoption of the federal natural water quality standards, studies of socio-economic factors in the localities where they will pertain should commence. The opportunity for verification or improvement of these standards, which may be indicated and perhaps dictated by socio-economic factors measured from the very beginning of the program, should not be missed. Data such as those indicated by the method proposed here, and perhaps others, will be required to continue the protection of the environment in a truly comprehensive way.

REFERENCES

1. Ackerman, E. A., and G. O. G. Löf. 1959. Technology in American Water Development, The Johns Hopkins Press, Baltimore.
2. Anon. 1966. Engineering News Record, Vol. 178, No. 1, August 4, p. 52.
3. Anon. 1966. "Water Reuse," Chemical and Engineering News, March 21, pp. 91-100.
4. Anon. 1967. "Companies Dig Deeper to Cut Pollution," Chemical and Engineering News, Vol. 54, No. 6, February 6, pp. 32-34.
5. Arrow, K. J. 1965. "Criteria for Social Investment," Water Resources Research, Vol. 1, No. 1, First Quarter, pp. 1-8.
6. ASCE Committee on National Water Policy. 1966. "Principles of a Sound National Water Policy," Civil Engineering, Vol. 36, No. 12, December, pp. 38-40.
7. Baxter, S. S. 1965. "Economic Considerations of Water Pollution Control," Journal of WPCF, Vol. 37, No. 10, October, pp. 1363-1369.
8. Bean, E. L. 1962. "Progress Report on Water Quality Criteria," Jour. AWWA, Vol. 54, No. 11, November, pp. 1313-1331.
9. Bell, G. R. 1965. "Removal of Soluble Iron by Filtration," Jour. AWWA, Vol. 57, No. 4, April, pp. 458-471.
10. Berry, A. E. 1966. "Frontiers in Wastewater Management: Administrative," Journal of WPCF, Vol. 38, No. 5, May, pp. 762-773.
11. Bramhall, D. F., and E. S. Mills. 1966. "Alternative Methods of Improving Stream Quality: An Economic and Policy Analysis," Water Resources Research, Vol. 2, No. 3, Third Quarter, pp. 355-363.
12. Bramhall, D. F., and E. S. Mills. 1966. "A Note on the Asymmetry between Fees and Payments," Water Resources Research, Vol. 2, No. 3, Third Quarter, pp. 615-616.
13. Brandt, K. 1961. "Water Pollution Control and Its Challenge to Political Economic Research," Proceedings, The National Conference on Water Pollution, December 12-14, 1960, U. S. Government Printing Office, Washington, D. C., pp. 474-484.
14. Burns, J. L. 1967. "Changing Directions in American Education: Our Era of Opportunity," Saturday Review, January 14, pp. 38-39.

15. Bylund, H. B. 1966. "The Human Factor and Changes in Water Usage Patterns," Water Resources Research, Vol. 2, No. 3, Third Quarter, pp. 365-369.
16. Campbell, E. W. 1966. "Social and Economic Factors in Highway Location," Journal of the Highway Division, ASCE, Vol. 92, No. HW2, Proc. Paper 4926, October, pp. 35-48.
17. Carlson, E. 1966. in Wall Street Journal, Vol. XLVI, No. 219, August 23.
18. Chatters, C. H. 1958. "Financing Water Utilities in 1958," Jour. AWWA, Vol. 50, No. 6, June, pp. 709-713.
19. Ciardi, J. 1967. "Manner of Speaking: Long Water Going," Saturday Review, March 18, p. 15.
20. Cleary, E. J. 1961. "Water Pollution Control Practice in an Expanding Economy," Seminar Papers on Waste Water Treatment and Disposal, Boston Society of Civil Engineers, Sanitary Section, Boston, Mass., pp. 218-230.
21. Cleary, E. J. 1966. "Development of Water-Quality Standards," Highlights, Vol. 3, No. 4, Water Pollution Control Federation, p. 3.
22. "Coliform Standards for Recreational Waters." 1963. Progress Report of Public Health Activities Committee, San. Engr. Division, ASCE, Journal of the Sanitary Engineering Division, ASCE, Vol. 89, No. SA4, August, Proc. Paper 3617, pp. 57-94; "Closure," Vol. 90, No. SA5, October, 1964, pp. 47-49.
23. Coulter, J. B. 1966. "What Is a Comprehensive Water Pollution Control Program?," Journal of WPCF, Vol. 38, No. 6, June, pp. 1011-1022.
24. Culp, G., and A. Slechta. 1966. "Plant Scale Reactivation and Reuse of Carbon in Wastewater Reclamation," Water and Sewage Works, Vol. 113, No. 11, November, pp. 425-431.
25. Davis, N. E. 1966. "Stream Monitoring in Galveston Bay," Public Works, Vol. 97, No. 5, May, pp. 118-120.
26. DeBoer, L. M., and T. E. Larson. 1961. "Water Hardness and Domestic Use of Detergents," Jour. AWWA, Vol. 53, No. 7, July, pp. 809-822.
27. DeFalco, P., Jr. 1965. "A Comprehensive Water Pollution Control Program for the Hudson-Champlain and Metropolitan Coastal River Basins," presented at meeting of Central Jersey Section of the New Jersey Water Pollution Control Association, March 31, 1965, 6 p.

28. Deininger, R. A. 1965. "Water Quality Management--The Planning of Economically Optimal Pollution Control Systems," Proceedings of the First Annual Meeting of the American Water Resources Association, American Water Resources Association, Urbana, Illinois, pp. 254-282.
29. Dixon, J. W. 1964. "Water Resources. Part I. Planning and Development," in Handbook of Applied Hydrology, Ven Te Chow, editor-in-chief, McGraw-Hill Book Company, New York, pp. 26-1 to 26-29.
30. Dorfman, R. 1965. "Formal Models in the Design of Water Resources Systems," Water Resources Research, Vol. 1, No. 3, Third Quarter, pp. 329-336.
31. Easthagen, J. H., V. Skrylov, and A. L. Purvis. 1965. "Development of Refinery Wastewater Control at Pascagoula, Mississippi," Journal of WPCF, Vol. 37, No. 12, December, pp. 1671-1678.
32. Eliassen, R. 1963. "Challenges in Research and Development," Journal of WPCF, Vol. 35, No. 3, March, pp. 267-274.
33. Environmental Pollution Panel, President's Science Advisory Committee. 1965. Restoring the Quality of Our Environment, The White House, Washington, D. C., 317 p.
34. Executive Office of the President, Bureau of the Budget, Circular A-47, December 31, 1952.
35. Fair, G. M., and J. C. Geyer. 1954. Water Supply and Waste-Water Disposal, John Wiley & Sons, Inc., New York, 973 p.
36. Fair, G. M., J. C. Geyer, and D. A. Okun. 1966. Water and Wastewater Engineering: Volume 1. Water Supply and Wastewater Removal, John Wiley & Sons, Inc., New York, pp. 2-26 to 2-27.
37. Falk, L. H., and W. J. Stober. 1966. The Measurement and Comparison of Costs for Alternative Water Replacement Projects, Louisiana Water Resources Research Institute, Bulletin 2, Louisiana State University, Baton Rouge, 33 p.
38. Faust, R. J. 1963. "What is Quality Water?," Proceedings, Fifth Sanitary Engineering Conference, Quality Aspects of Water Distribution Systems, Illinois State Department of Public Health and University of Illinois, January 29-30, 1963, Univ. of Ill. Engineering Experiment Station Circular No. 81, pp. 6-8.
39. Frankel, R. J. 1965. Economic Evaluation of Water Quality--An Engineering-Economic Model for Water Quality Management, First Annual Report, University of California, Sanitary Engineering Research Laboratory Report No. 65-3, 167 p.

40. Frankel, R. J. 1965. "Water Quality Management: Engineering-Economic Factors in Municipal Waste Disposal," Water Resources Research, Vol. 1, No. 2, Second Quarter, pp. 173-186.
41. Fuller, B. 1966. "What I Have Learned: How Little I Know," Saturday Review, November 12, pp. 29-31, 67-70.
42. Gabrielson, I. N. 1961. "Pollution Is a People Problem," Proceedings, The National Conference on Water Pollution, December 12-14, 1960, U. S. Government Printing Office, Washington, D. C., pp. 23-29.
43. Gabrielson, I. N. 1965. "Water Quality Criteria--Stream vs. Effluent Standards--Conservation Views," Journal of WPCF, Vol. 37, No. 3, March, pp. 295-300.
44. Galbraith, J. K. 1964. "Economics and the Quality of Life," Science, Vol. 145, pp. 117-123.
45. Glendinning, W. 1964. Engineering Economics and Practice, William Glendinning, Bayside, New York, 124 p.
46. Gotaas, H. B. 1966. "Frontiers in Wastewater Management: Technological," Journal of WPCF, Vol. 38, No. 5, May, pp. 745-754.
47. Grant, E. L. 1950. Principles of Engineering Economy, Third Edition, The Ronald Press Company, New York, 623 p.
48. Green, R. S., D. P. Dubois, and C. W. Tutwiler. 1965. "Data Handling Systems in Water Pollution Control," Conference Preprint 159, ASCE Water Resources Engineering Conference, Mobile, March 8-12, 25 p.
49. Green, R. S. 1966. "Pollution Surveillance and Water Quality Monitoring in the United States," Paper presented at the 94th Annual Meeting of the American Public Health Association, November 2, San Francisco, 11 p.
50. Griffin, A. E. 1960. "Significance and Removal of Manganese in Water Supplies," Jour. AWWA, Vol. 52, No. 10, October, pp. 1326-1334.
51. Gross, W. M. 1965. "What Is Pollution--to a Lawyer?," ASCE Water Resources Engineering Conference, Mobile, March 8-12, Conference Preprint 179, 7 p.
52. Haney, P. D. 1966. "What Is Pollution? An Engineer's Viewpoint," Journal of the Sanitary Engineering Division, ASCE, Vol. 92, No. SA1, February, pp. 109-113.

53. Hanson, L. E. 1964. "Quality and Cost Evaluation of Treatment Processes for a Specific Water," Jour. AWWA, Vol. 56, No. 5, May, pp. 535-542.
54. Hartung, H. O. 1965. "Practical Considerations in Defining Quality Water," Jour. AWWA, Vol. 57, No. 3, March, pp. 286-292.
55. Howe, C. W. 1966. "Broad Horizons in Water Resource Planning and Investment," Water Resources Research, Vol. 2, No. 4, Fourth Quarter, pp. 843-847.
56. Howe, E. D. 1958. "Progress in Conversion of Saline Water," Jour. AWWA, Vol. 50, No. 3, March, pp. 319-330.
57. Howson, L. R. 1962. "Economics of Water Softening," Jour. AWWA, Vol. 54, No. 2, February, pp. 161-166.
58. Hubbard, E. C. 1965. "Water Quality Criteria--Stream vs. Effluent Standards--Stream Standards," Journal of WPCF, Vol. 37, No. 3, March, pp. 308-313.
59. Hufschmidt, M. F. 1965. "Field Level Planning of Water Resources Systems," Water Resources Research, Vol. 1, No. 2, Second Quarter, pp. 147-163.
60. Imhoff, K., and G. M. Fair. 1956. Sewage Treatment, 2nd Edition, John Wiley & Sons, Inc., New York, 338 p.
61. James, L. D. 1965. "Techniques in the Application of Engineering Economy to Water Resources Development," Proceedings of the First Annual Meeting of the American Water Resources Association, American Water Resources Association, Urbana, Illinois, pp. 120-127.
62. Johnson, B. W., and F. H. Dow, Jr. 1966. "Frontiers in Wastewater Management: Financial," Journal of WPCF, Vol. 38, No. 5, May, pp. 754-762.
63. Joint Committee of APHA, ASCE, AWWA, FSWA. Undated. Glossary: Water and Sewage Control Engineering, 274 p.
64. Jones, J. R. E. 1964. Fish and River Pollution, Butterworth, Inc., Washington, D. C., 203 p.
65. Jones, L. L., Jr. 1965. "Textile Waste Treatment at Canton Cotton Mills," Journal of WPCF, Vol. 37, No. 12, December, pp. 1693-1695.
66. Kamien, M. I., N. L. Schwartz, and F. T. Dolbear. 1966. "Asymmetry between Charges and Bribes," Water Resources Research, Vol. 2, No. 1, First Quarter, pp. 147-151.

67. Kerri, K. D. 1966. "An Economic Approach to Water Quality Control," Journal of WPCF, Vol. 38, No. 12, December, pp. 1883-1897.
68. Klein, L. 1962. River Pollution. II. Causes and Effects, Butterworths, London, 456 p.
69. Kneese, A. V. 1962. Water Pollution--Economic Aspects and Research Needs, Resources for the Future, Inc., Washington, D. C., 107 p.
70. Kneese, A. V. 1964. The Economics of Regional Water Quality Management, The Johns Hopkins University Press, Baltimore, 215 p.
71. Krutilla, J., and G. Eckstein. 1958. Multiple Purpose River Developments, Studies in Applied Economic Analysis, The Johns Hopkins University Press, Baltimore, 301 p.
72. Langdon, P. E., Jr. 1966. "Economic Aspects of Iron Removal and Ion Exchange Softening," Proceedings, Eighth Sanitary Engineering Conference, Cost Aspects of Water Supply, University of Illinois Bulletin Vol. 63, No. 121, pp. 96-108.
73. Larson, T. E., and B. O. Larson. 1957. Quality of Surface Waters in Illinois, Illinois State Water Survey Bulletin 45, Urbana, 135 p.
74. Larson, T. E. 1963. Mineral Content of Public Ground-Water Supplies in Illinois, Illinois State Water Survey Circular 90, Urbana, 28 p.
75. Lawrance, C. H. 1964. "Design Aspects of Lompoc Water Treatment Plant," Journal of the Sanitary Engineering Division, ASCE, Vol. 90, No. SA6, December, pp. 81-113.
76. Lawrance, C. H. 1965. "Quality Improvements for Lompoc, Calif.," Jour. AWWA, Vol. 57, No. 5, May, pp. 607-624.
77. Liebman, J. C., and W. R. Lynn. 1966. "The Optimal Allocation of Stream Dissolved Oxygen," Water Resources Research, Vol. 2, No. 3, Third Quarter, pp. 581-591.
78. Lisovitch, V. V. 1966. "Methods of Economic Evaluation as Applied to Studies and Projects," Proceedings of the Water Resources Seminars 1963-1966, University of Delaware, Department of Civil Engineering, Newark, pp. 29-68.
79. Logan, J. A., W. D. Hatfield, G. S. Russell, and W. R. Lynn. 1962. "An Analysis of the Economics of Wastewater Treatment," Journal of WPCF, Vol. 34, No. 9, September, pp. 860-882.

80. Magnuson, H. J. 1966. "The Total Impact of the Environment on Man," Man's Environment in the Twenty-first Century, edited by Charles M. Weiss, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, Publication No. 105, Second Printing, pp. 20-36.
81. Meron, A., M. Rebhun, and B. Sless. 1965. "Quality Changes as a Function of Detention Time in Wastewater Stabilization Ponds," Journal of WPCF, Vol. 37, No. 12, December, pp. 1657-1670.
82. Murdoch, J. H., Jr. 1965. "75 Years of Too Cheap Water--9 Years Later," Jour. AWWA, Vol. 57, No. 8, August, pp. 943-947.
83. Murphy, E. F. 1961. Water Purity, University of Wisconsin Press, Madison, 212 p.
84. McBeath, B. C., and R. Eliassen. 1966. "Sensitivity Analysis of Activated Sludge Economics," Journal of the Sanitary Engineering Division, ASCE, Vol. 92, No. SA2, April, pp. 147-167.
85. McCallum, G. E. 1963. "Advanced Waste Treatment and Water Reuse," Journal of WPCF, Vol. 35, No. 1, January, pp. 1-10.
86. McCallum, G. E. 1965. "Water Quality Criteria--Stream vs. Effluent Standards--Water Quality Criteria Development," Journal of WPCF, Vol. 37, No. 3, March, pp. 313-315.
87. McGauhey, P. H. 1965. "Folklore in Water Quality Standards," Civil Engineering, Vol. 35, No. 6, June, pp. 70-71.
88. McKee, J. E. 1960. "The Need for Water Quality Criteria," Proceedings of Conference on Physiological Aspects of Water Quality, September 8-9, Washington, D. C., U. S. Public Health Service, pp. 15-26.
89. McKee, J. E., and H. W. Wolf, editors. 1963. Water Quality Criteria, The Resources Agency of California, State Water Quality Control Board, Pub. No. 3-A, 548 p.
90. McMurrin, S. M. 1967. "Changing Directions in American Education: What Tasks for the Schools?," Saturday Review, January 14, pp. 40-43.
91. National Academy of Sciences - National Research Council. 1966. Alternatives in Water Management, Publication 1408, Washington, D. C., 52 p.
92. National Academy of Sciences - National Research Council. 1966. Waste Management and Control, Publication 1400, Washington, D. C., 257 p.

93. Ockerhausen, R. W. 1965. "Use of Liquid Alum in Water Plants," Jour. AWWA, Vol. 57, No. 3, March, pp. 309-313.
94. Pfeffer, J. T. 1965. "The Detergent Problem Today," Public Works, Vol. 96, No. 6, June, pp. 118-120.
95. "Policies, Standards, and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Land Resources." 1962. 87th Congress, 2nd Session, Senate Document 97, 13 p.
96. Prest, A. R., and R. Turvey. 1965. "Cost-Benefit Analysis: A Survey," The Economic Journal, December, pp. 683-731.
97. "Proposed Practices for Economic Analysis of River Basin Projects," Report of the Subcommittee on Benefits and Costs, Federal Inter-Agency River Basin Committee, May 1950, revised by Subcommittee on Evaluation Standards, May 1958, 56 p.
98. Rehm, L. F., and W. H. Plautz. 1966. "Various Costs of Clarification, Filtration, and Lime Softening," Proceedings, Eighth Sanitary Engineering Conference, Cost Aspects of Water Supply, University of Illinois Bulletin Vol. 63, No. 121, pp. 109-121.
99. Roesler, W. G. 1966. "History and Techniques of Urban Planning," Journal of the Urban Planning and Development Division, ASCE, Proc. Paper 4810, Vol. 92, No. UPI, May, pp. 5-12.
100. Rowan, P. P., K. H. Jenkins, and D. W. Butler. 1960. "Sewage Treatment Construction Costs," Journal of WPCF, Vol. 32, No. 6, June, pp. 594-604.
101. Rowan, P. P., K. L. Jenkins, and D. H. Howells. 1961. "Estimating Sewage Treatment Plant Operation and Maintenance Costs," Journal of WPCF, Vol. 33, No. 2, February, pp. 111-121.
102. Ruskin, J. H. 1964. "Discussion of Coliform Standards for Recreational Waters," Journal of the Sanitary Engineering Division, ASCE, Vol. 90, No. SA2, April, p. 39.
103. Sherwani, J. K. 1966. "Urban and Industrial Water Supply: Prospects and Possibilities," Man's Environment in the Twenty-first Century, edited by Charles M. Weiss, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, Publication No. 105, Second Printing, pp. 96-128.
104. Sport Fishing Institute. 1966. "SFI Bulletin," Sport Fishing Institute, Washington, D. C., No. 176, July, 8 p.

105. Stephan, D. G. 1965. "Water Renovation--Some Advanced Treatment Processes," Civil Engineering, Vol. 35, No. 9, September, pp. 46-49.
106. Stevens, J. B. 1966. "Recreation Benefits from Water Pollution Control," Water Resources Research, Vol. 2, No. 2, Second Quarter, pp. 167-182.
107. Straub, C. P. 1964. Low-level Radioactive Wastes: Their Handling, Treatment, and Disposal, Division of Technical Information, U. S. Atomic Energy Commission, 430 p.
108. Stroud, R. H. 1965. "What Is Pollution--to a Conservationist?," ASCE Water Resources Engineering Conference, Mobile, March 8-12, Conference Preprint No. 169, 9 p.
109. Subcommittee on Science, Research, and Development. 1964. Environmental Pollution: A Challenge to Science and Technology, Committee on Science and Astronautics, U. S. House of Representatives, 89th Congress, 2nd Session, U. S. Government Printing Office, Washington, D. C., 60 p.
110. Symons, J. M., S. R. Weibel, and G. G. Robeck. 1964. Influence of Impoundments on Water Quality, A Review of Literature and Statement of Research Needs, U. S. Department of Health, Education, and Welfare, Public Health Service, Cincinnati, pp. 59-61.
111. Tennessee Valley Authority. 1966. Nature's Constant Gift: A Report on the Water Resources of the Tennessee Valley, Tennessee Valley Authority, Knoxville, 72 p.
112. Thomann, R. V. 1965. "Recent Results from a Mathematical Model of Water Pollution Control in the Delaware Estuary," Water Resources Research, Vol. 1, No. 3, Third Quarter, pp. 349-359.
113. Thomas, H. A., Jr. 1964. "The Animal Farm: A Mathematical Model for the Discussion of Social Standards for Control of the Environment," Jour. AWWA, Vol. 56, No. 9, September, pp. 1087-1091.
114. Thomas, H. E. 1965. "Water Resources Commentary: Water Problems," Water Resources Research, Vol. 1, No. 3, Third Quarter, pp. 435-445.
115. Thursby, J. W. 1966. "Some Economic Implications of Water Quality Management," Proceedings of the National Symposium on Quality Standards for Natural Waters, University of Michigan, School of Public Health, Ann Arbor, pp. 55-62.
116. Tsivoglou, E. C., E. D. Harward, and W. M. Ingram. 1957. "Stream Surveys for Radioactive Waste Control, Paper No. 57-NESC-21, 2nd Nuclear Engineering and Science Conference, March 11-14, Philadelphia, The American Society of Mechanical Engineers, New York, 12 p.

117. U. S. Department of Health, Education, and Welfare, Public Health Service. 1962. National Water Quality Network: Annual Compilation of Data, October 1, 1961 - September 30, 1962, Public Health Service Publication No. 663, Washington, D. C., 909 p.
118. U. S. Department of Health, Education, and Welfare. 1962. Public Health Service Drinking Water Standards, U. S. Government Printing Office, Washington, D. C., PHS Publication No. 956, 61 p.
119. U. S. Department of Health, Education, and Welfare. 1963. Proceedings of Conference on Interstate Pollution of the Coosa River (Georgia-Alabama), Rome, Georgia, August 27, 1963, 370 p.
120. U. S. Department of Health, Education, and Welfare, Public Health Service. 1963. Sewage Treatment Plant Construction Cost Index, U. S. Government Printing Office, Washington, D. C., 33 p.
121. U. S. Department of Health, Education, and Welfare, Public Health Service. 1964. Modern Sewage Treatment Plants--How Much Do They Cost?, U. S. Government Printing Office, Washington, D. C., 37 p.
122. U. S. Department of the Interior, Federal Water Pollution Control Administration. 1966. Guidelines for Establishing Water Quality Standards for Interstate Waters (Under the Water Quality Act of 1965, Public Law 89-234), May, 12 p.
123. "Water Quality Act of 1965." Public Law 89-234, signed into law October 2, 1965.
124. Weaver, L. 1966. "Stream Surveillance Programs," Journal of WPCF, Vol. 38, No. 8, August, pp. 1334-1344.
125. Weber, E. W. 1963. "River Basin Planning Background," Seminar on River Basin Planning, Ft. Belvoir, Va., 27-31 May, 1963, pp. 1-9.
126. Webster's New World Dictionary of the American Language, College Edition, The World Publishing Company, Cleveland, 1960, 1724 p.
127. Weinkauff, H. C. C., and C. P. Lindner. 1965. "Current Concepts of Water Resources Project Formulation and Their Application to Hydro-Development in the Southeast," ASCE Water Resources Engineering Conference, Mobile, March 8-12, Conference Preprint 139, 27 p.
128. Weston, R. F. 1964. "A National Industrial Viewpoint: The Value and Use of Water Quality Criteria to Protect Aquatic Life," Water and Sewage Works (Reference Number), November 30, pp. R-276 to R-279.
129. Weston, R. F. 1966. "Management of Pollution Sources to Meet Standards, Industrial Waste Sources," Proceedings of the National Symposium on Quality Standards for Natural Waters, University of Michigan, School of Public Health, Ann Arbor, pp. 297-302.

130. Whipple, W., Jr. 1966. "Economic Basis for Effluent Charges and Subsidies," Water Resources Research, Vol. 2, No. 1, First Quarter, pp. 159-164.
131. Williamson, J. N., A. H. Heit, and C. Calmon. 1964. Evaluation of Various Adsorbents and Coagulants for Waste-Water Renovation, AWTR-12, U. S. Public Health Service Publication No. 999-WP-14, Robert A. Taft Sanitary Engineering Center, Cincinnati, 91 p.
132. Wilson, R. N. 1966. "Sociological Factors," Man's Environment in the Twenty-first Century, edited by Charles M. Weiss, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, Publication No. 105, Second Printing, pp. 303-314.
133. Wolman, A. 1960. "Conference Evaluation," Proceedings of Conference on Physiological Aspects of Water Quality, September 8-9, Washington, D. C., U. S. Public Health Service, pp. 233-238.
134. Woodward, R. L. 1965. "At MacDonald's Farm," Jour. AWWA, Vol. 57, No. 1, January, pp. 120-121.
135. Worley, J. L., F. J. Burgess, and W. W. Towne. 1965. "Identification of Low-Flow Augmentation Requirements for Water Quality Control by Computer Techniques," Journal of WPCF, Vol. 37, No. 5, May, pp. 659-673.
136. Young, G. K., Jr., T. Popowchak, and G. W. Burke, Jr. 1965. "Correlation of Degree of Pollution with Chemical Costs," Jour. AWWA, Vol. 57, No. 3, March, pp. 293-297.
137. Zapp, J. A., Jr. 1960. "Minimal Effects of Organic Water Contaminants," Proceedings of Conference on Physiological Aspects of Water Quality, September 8-9, Washington, D. C., U. S. Public Health Service, pp. 167-174.

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